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A Physiological Evaluation of the Soldier Integrated Protective Ensemble (SIPE) Clothing System

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13. ABSTRACT (Maximum 200 words)

The Soldier Integrated Protective Ensemble (SIPE) program is the initial step in developing an integrated modular clothing and equipment system for combat ground troops. This system will increase lethality, mobility, survivability, command and control and overall protection of the troops. This environmental chamber study compared physiological responses of volunteers exercising in MOPP 0, MOPP 1, and MOPP 4 with equivalent SIPE configurations, including SIPE 4 with and without ambient air microclimate cooling (MCC). Responses to all uniforms were compared over 100 minutes of continuous treadmill walking at 30.0°C, 50% rh. Responses to MOPP 4 and SIPE 4 with no cooling were also compared over 100 minutes at 18.5°C, 50% rh. Responses to MOPP 4 and SIPE 4 MCC were compared over four hours of intermittent work-rest cycles at 30.0°C, 50% rh. There were no differences between MOPP 0 and SIPE 0, MOPP 1 and SIPE 1, and MOPP 4 and SIPE 4 with no cooling (in both environments). Core temperature, skin temperature, heat storage, and heart rate were lower in SIPE 4 MCC than in MOPP 4; while evaporative cooling was greater in SIPE 4 MCC than in MOPP 4. Three volunteers completed the 4-hour tests in SIPE 4 MCC with similar advantageous trends apparent from the cooling. It is concluded that the SIPE clothing did not increase thermal strain compared to equivalent MOPP levels, and MCC, (although increasing uniform weight by approximately 10 kg) reduced thermal strain at 30.0°C.

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A PHYSIOLOGICAL EVALUATION OF THE SOLDIER INTEGRATED PROTECTIVE ENSEMBLE (SIPE) CLOTHING SYSTEM

by

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February 1993

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Technical support in fitting, operating and maintaining the equipment worn by the soldiers was provided by Ms. Cynthia Blackwell, Ms. Heidi Danziger and Ms. Cynthia Mooney of the SIPE office.

EXECUTIVE SUMMARY

The Soldier Integrated Protective Ensemble (SIPE) program was established by the Department of the Army as an Advanced Technology Demonstration in 1990. SIPE is the initial step in developing a Soldier System to create an integrated modular design for the soldier's clothing and equipment. This Soldier System is designed to increase the lethality, mobility, survivability, command and control and overall protection of the ground troop. All clothing and equipment in the SIPE program was developmental and not hardened hardware ready for fielding. This controlled, environmental chamber study compared physiological responses of volunteers exercising in MOPP 0, MOPP 1, and MOPP 4 with equivalent SIPE configurations, including the SIPE 4 configuration with and without ambient air microclimate cooling. Tests were conducted at 30.0°C (86°F), 50% rh and 18.5°C (65°F), 50% rh. Responses to all uniform configurations were made over 100 minutes of continuous treadmill walking at 30.0°C. Responses to MOPP 4 and SIPE 4 with no cooling were compared at 18.5°C. MOPP 4 was compared to SIPE 4 with ambient air microclimate cooling over four hours of intermittent work-rest cycles. There were no significant differences in physiological responses between MOPP 0 and SIPE 0, MOPP 1 and SIPE 1, and MOPP 4 and SIPE 4 with no cooling (in both the 30.0°C and 18.5°C environments) during the 100-minute tests. Core temperature, skin temperature, calculated heat storage, and heart rate were significantly lower in SIPE 4 with ambient air microclimate cooling than in MOPP 4; while evaporative cooling was significantly greater than in MOPP 4. Three volunteers completed the 4-hour tests with similar advantageous trends from microclimate cooling with SIPE 4 apparent. It is concluded that the SIPE clothing did not increase thermal strain compared to equivalent MOPP levels, and ambient air microclimate cooling, (although increasing the overall uniform weight by approximately 10 kg) served to reduce thermal strain at 30.0°C.

INTRODUCTION

As a part of the Soldier Modernization Plan, the Department of the Army initiated a 6.3A Advanced Technology Demonstration (ATD) in 1990. This ATD was the initial step in the development of a Soldier System to provide future combat troops the capabilities to defeat the enemy at greater distances with enhanced survivability. The lead organization for the ATD was the U.S. Army Natick Research, Development and Engineering Center (NATICK). This ATD evaluated the ability of the Soldier Integrated Protective Ensemble (SIPE), to increase the lethality, command and control functions, and overall protection of the ground troop. The objective of the SIPE ATD was to use emerging and advanced technologies to design, create and demonstrate the capabilities of a modular fighting system for the ground soldier in a tactical environment. SIPE attempted to create an integrated fighting system of the soldier's clothing and equipment in order to improve combat effectiveness and enhance survivability. The baseline system to be improved upon were the uniform components which comprise the current Mission Oriented Protective Postures 0-4 (MOPP), and combat equipment (designed independently of the uniform) which must be carried by ground troops. The SIPE modular system was designed to optimize the balance between performance and protection while not overburdening the soldier with unnecessary equipment. The SIPE equipment was not hardened prototype hardware ready for immediate fielding, but rather developmental.

As part of the SIPE ATD to enhance individual protection, Natick specified layers of clothing which can be worn in varied configurations. These are potential replacements for the current battledress uniform (BDU), battledress overgarment (BDO), body armor, and load bearing equipment (LBE) which are worn in various configurations in the current MOPP 0-4 postures dependent on the tactical environment. The current BDO has high thermal resistance and low water vapor permeability. The heat stress associated with wearing this nuclear/biological/chemical (NBC) protective clothing results in high skin temperature, heart rate, sweating rate and core temperature which limit soldier performance (1,3,4,5,6).

SIPE provides more clothing configuration options than the current MOPP system which allows the SIPE equipped soldier to meet varied protective needs while

minimizing heat strain. The SIPE system was designed for use by troops in temperate environments. The system begins with a Coolmax® t-shirt next to the skin to help wick perspiration away from the skin surface. The next layer, which is worn when there is potential exposure to a chemical vapor threat, is a chemical vapor undergarment (CVU) made of cotton and polyester with carbon spheres. This is covered by the Advanced Combat Uniform (ACU) (replacing the current Temperate Battle Dress Uniform) which is both flame resistant (PROBAN®) and water repellant (Quarpel®). The Advanced Shell Garment (ASG), which completes the basic uniform components, is made of nylon/Gore-tex® components along with additional water repellant treatment, and serves to protect against liquid chemical threat as well as serving as standard wet weather gear. Standard SIPE equipment also includes a new combat glove, a new non butyl rubber chemical glove and a new Gore-tex® lined combat boot with chemical protective gaiter to replace the green vinyl overboot. The new ballistic vest includes titanium plates to increase protective level and has built in pockets for carrying the standard rifleman's load. The SIPE system also includes a newly designed Load Bearing Component (LBC) for carrying some of the electronics integral to the system as well as some of the combat load

Additionally, SIPE includes a portable cooling unit for delivering filtered ambient air to a torso microclimate vest (which fits in the Cool-max® t-shirt) and to a protective mask to aid the soldier's ability to thermoregulate through convective and evaporative heat loss. Use of ambient cooling provides variable maximal cooling rates dependent on the ambient conditions. In one previous study with soldiers exercising at 425 watts while wearing MCPP 4 in tropic conditions (35°C, 70% rh), volunteers with ambient cooling exercised 40% longer and with lower heat storage than volunteers in control experiments with no cooling (1). In that the SIPE system was designed for use in temperate environments, which would typically have less extreme environmental conditions than the tropic condition cited, it was expected that an ambient air cooling system would aid in significantly reduced heat storage and improved performance.

The entire SIPE ensemble (including all electronics to increase mobility and lethality) was field demonstrated at Ft. Benning, GA during the fourth quarter FY 92. This laboratory study was conducted prior to the field demonstration. This provided the SIPE office with physiological data during exercise, for soldiers wearing SIPE

uniform configurations in temperatures similar to those found at Ft. Benning during September and early December (1990 Light Data and Climatology Report for Ft. Benning, GA).

Specifically, this research compared the thermoregulatory responses and performance of male soldiers wearing MOPP and SIPE clothing in equivalent NBC and non-NBC configurations during moderate exercise in two environments. The equivalent clothing levels were based on the level of protection against NBC threat. The test environments were a warm (30.0°C, 86°F, 50% rh) environment with minimal dry heat loss in MOPP 4, and a cool (18.5°C, 65°F, 50% rh) environment which allowed increased dry and evaporative heat loss in MOPP 4. Experiments in the warm environment included SIPE with ambient cooling in one MOPP 4 equivalent configuration. These experiments provided comparative information which determined if heat strain was reduced and performance was improved in soldiers wearing the developmental system relative to the MOPP system. Because the clothing system is developmental with ongoing refinements, there are potential differences in the fabric weights, and amounts of water repellant and flame resistant chemicals used in the fabric for these experiments and the clothing worn by volunteers at the Ft. Benning Field Demonstration.

METHODS

SUBJECTS

Eight male soldiers selected from members of the NATICK test volunteer platoon or recruited from military units at other posts, served as volunteer subjects. They were fully informed of the purpose, procedures, potential risks of the study and signed a statement of informed consent. After completing medical examinations to assure there were no underlying medical problems, the volunteers began preliminary testing. Investigators adhered to guidelines established for research in humans in USARIEM M 40-68, AR 70-25 and USAMRDC 70-25 on the Use of Volunteers in Research.

STUDY DESIGN

Preliminary testing consisted of anthropometric measures (height, weight, estimate of per cent body fat by subcutaneous skinfold thickness at four sites (2)), and maximal oxygen uptake, all of which provided descriptive data on the volunteers. Maximal oxygen uptake was determined using a continuous effort treadmill test. Each volunteer's running speed was determined from his heart rate response to a five-minute warm-up walk at 1.56 $m \cdot sec^{-1}$ (3.5 mph) at a 10% grade. If the heart rate response was $\geq$145 $b \cdot min^{-1}$, the treadmill speed for the maximal test was set at 2.68 $m \cdot sec^{-1}$ (6.0 mph), and if the heart rate response was <145 $b \cdot min^{-1}$ the treadmill speed was set at 3.13 $m \cdot sec^{-1}$ (7.0 mph). The initial treadmill grade was 0% and was increased by 2.5% increments every 1.5 minutes while the volunteers continued to run. Continuous oxygen uptake values were collected and analyzed using a Sensormedics 2900 Metabolic Cart. Documented criteria (7,9) were used for determination of $\dot{V}O_2max$, or volunteers were stopped upon reaching a heart rate of 210 $b \cdot min^{-1}$ as established by the USARIEM Type Protocol. Nude weights were taken each morning before breakfast for five days to establish baseline euhydrated weights for the volunteers before they began exercising in a hot environment. The volunteers' average age was 20 ± 1 yr, average height was 1.76 ± 0.05 m, average weight was 73.1 ± 6.2 kg, average body fat was 14.7 ± 5.4 % and $\dot{V}O_2max$ was 57.3 ± 4.3 $ml \cdot kg^{-1} \cdot min^{-1}$ (n=7)[1]. These characteristics represented young men of average size and body composition, with an average to above average level of aerobic fitness.

The volunteers were familiarized with the equipment and completed a seven day exercise-heat acclimation program before experiments began. On one morning, subjects were fitted to the NBC protective clothing to be worn during experimental tests. They then took part in two familiarization sessions on the treadmill wearing both standard and SIPE uniforms in the configurations to be worn during the experiments. Appendix A contains the complete description of all SIPE components, while Appendix B lists all the MOPP and SIPE components worn and carried in each experiment. The familiarization sessions were conducted in an environmental chamber at 18-20°C and lasted approximately 3 hours each day. The familiarization

[1] One subject was not medically cleared to participate in the maximal oxygen uptake test

sessions included collection of metabolic measurements (open circuit spirometry) at various treadmill speeds and grades, to determine the appropriate treadmill speed and grade for experimental tests. A speed of 1.34 $m \cdot sec^{-1}$ (3.0 mph) with a 3% grade was chosen as appropriate for testing as it elicited a mean energy expenditure of 450-550 watts depending on the uniform configuration being worn.

The volunteers then participated in a seven-day, exercise-heat acclimation program. Acclimation consisted of treadmill walking at 1.56 $m \cdot sec^{-1}$ on a 4% grade for 100 consecutive minutes. Environmental conditions during heat acclimation were 43.0°C T_{db}, 15.0°C T_{dp}, 20% rh and wind speed 1.1 $m \cdot sec^{-1}$. During acclimation, volunteers wore shorts and athletic shoes or combat boots. They were instrumented for the monitoring of heart rate (HR) and core temperature (T_{re}). They wore intact M40 protective masks for progressively longer periods of time on each acclimation day (from 10 to 60 minutes) to allow familiarization with wearing the protective mask for prolonged periods. Volunteers were encouraged to drink sufficient water to maintain euhydration throughout each acclimation session. Completion of this program resulted in changes in the volunteers' thermoregulatory systems (improved heat loss ability, decreased heart rate and decreased core temperature) to better allow them to complete exercise sessions in a hot environment.

The experimental tests were conducted in two environments; 30.0°C T_{db}, 18.5°C T_{dp}, 50% rh, and 18.5°C T_{db}, 7.5°C T_{dp}, 50% rh. Wind speed was 2.2 $m \cdot sec^{-1}$ (5.0 mph) for all experimental tests. Both environments allowed heat loss, thereby increasing the potential to observe differences between the two clothing systems. The warm environment caused heat strain in exercising, encapsulated volunteers, while allowing the potential for evaporative and convective cooling from ambient air microclimate cooling. The microclimate cooling system theoretically provided ~150 watts of cooling in the warm environment when operating at 100% efficiency. The cool environment reduced external heat stress to the volunteers, and increased convective and evaporative cooling potential to the environment through the semi-permeable clothing.

There were 11 experimental tests in standard MOPP and SIPE configurations. The basic clothing articles for both NBC and non-NBC SIPE configurations were the

chemical vapor undergarment (CVU), the advanced combat uniform (ACU), the advanced shell garment (ASG), and the ballistic vest. The ACU is designed to replace the current BDU while the CVU and ASG replace the BDO. These can be worn together or individually, depending on the type of chemical threat. The ASG can also serve as standard wet weather gear. Table 1 shows the baseline uniform for the 11 experimental tests. The volunteers performed nine experimental tests in the 30.0°C environment. Four experiments in the 30.0°C environment were conducted in currently fielded clothing configurations; one at MOPP 0, one at MOPP 1, and two at MOPP 4. Five experiments in the 30.0°C environment were conducted in SIPE configurations; one which approximates MOPP 0, one which approximates MOPP 1, and three which approximate MOPP 4. The SIPE equivalents to MOPP configurations were based on protective level, as determined by the project manager of the SIPE program. The three SIPE equivalents of MOPP 4 included two tests with ambient air microclimate cooling (MCC) and one with no cooling (NC). In the SIPE MCC experiments the volunteers needed to wear the load bearing component (LBC) to carry the portable MCC equipment. [One SIPE MCC experiment and one MOPP 4 experiment were different than all others in that they were 4-hour experiments using work-rest cycles and were completed by only three volunteers. Results of these two experiments are discussed informally in the Results/Discussion section.] Two experimental tests were conducted in the 18.5°C environment; one in MOPP 4 and one in SIPE 4 NC. The volunteers performed the 11 experimental tests in a counterbalanced order to avoid an order effect on results.

On each experimental test day, immediately after the nude weight at arrival (approximately 90 minutes before testing) the volunteers drank 400 ml of a glucose electrolyte solution with no further water until completion of the day's experiment. Additional water was offered to the volunteers during rest breaks in the 4-hour tests. Each of the primary experiments consisted of 100 minutes of continuous treadmill walking at ~450-550 W (pre-determined speed and grade of 1.34 $m \cdot sec^{-1}$, 3%). Appendix C shows the schedule for the 4-hour tests. Before being released at the end of each experimental test, the volunteers were required to drink sufficient water and fruit juice to return to their baseline weight.

Table 1.

	MOPP 0	MOPP 1	MOPP 4
MOPP CONFIGURATIONS	BDU OVER T-SHIRT, LYCRA® SHORTS, ARMOR, HELMET, BOOTS	BDO OVER T-SHIRT, LYCRA® SHORTS, ARMOR, HELMET, BOOTS	BDO OVER T-SHIRT LYCRA® SHORTS, ARMOR, HELMET, MASK, BOOTS, GLOVES, OVERSHOE

	SIPE 0	SIPE 1	SIPE 4 COOLING	SIPE 4 NO COOLING
SIPE CONFIGURATIONS	ACU OVER T-SHIRT, LYCRA® SHORTS, ARMOR, HELMET, BOOTS	T-SHIRT, LYCRA® SHORTS, CVU, ACU, ARMOR, HELMET, BOOTS	T-SHIRT, LYCRA® SHORTS, CVU, ASG, ARMOR, LBC/MCC, MASK, HELMET, GLOVES, BOOTS	T-SHIRT, LYCRA® SHORTS, CVU, ASG, ARMOR, MASK, HELMET, GLOVES, BOOTS

ALL SEVEN CONFIGURATIONS WERE WORN IN THE 30.0°C, 50% RH ENVIRONMENT; ONLY MOPP 4 AND SIPE 4 NO COOLING WERE WORN IN THE 18.5°C, 50% RH ENVIRONMENT.

Physiological Measurements

During all tests, T_{re} was measured by a flexible thermistor probe (YSI) inserted to a depth approximately 10 cm beyond anal sphincter. During the experiments in protective clothing, skin temperature (T_{sk}) was measured with a four site skin thermocouple harness (chest, arm, thigh, calf). Mean weighted skin temperature ($\bar{T}_{sk}$) was calculated using the weighting system of 0.3 chest, 0.3 arm, 0.2 thigh, and 0.2 calf (8). T_{re}, T_{sk} and $\bar{T}_{sk}$ were obtained by a computerized data collection system and printed every minute. Heart rate was obtained from an electrocardiogram (chest electrodes, CM5 placement), displayed continuously on an oscilloscope cardiotachometer unit and recorded every 10 minutes. Whole body sweating rate (M_{sw}) and evaporative cooling (E_{tot}) were calculated from the change in nude body weight during the entire exposure with corrections made for ingested water and water trapped within the garments as determined by dressed weights taken before and after heat exposure. Heat storage (S) in $W \cdot m^{-2}$ was calculated from the equation $S=[(m_b \cdot c_b)/A_D] \cdot (d\bar{T}_b/dt)$, where m_b is the mean body weight (kg) during the experiment; c_b is the specific heat constant 0.965 ($W \cdot h \cdot {}^\circ C^{-1} \cdot kg^{-1}$); A_D is the DuBois surface area (m^2); $d\bar{T}_b$ *is the change in mean body temperature* (°C) *where* $\bar{T}_b = 0.2 \cdot \bar{T}_{sk} + 0.8 \cdot T_{re}$; and dt is the exposure time (h) of the experiment. Open circuit spirometry was used to measure metabolic rates during the familiarization sessions, and on all experimental test days except the four-hour experiments. The test design of the four-hour experiments precluded acquiring steady state data at most work levels. Metabolic rates for the four-hour experiments were approximated from data collected during the familiarization trials, and from resting data collected while wearing the appropriate uniform configurations.

Statistical Analyses

Analyses of variance with repeated measures on the independent variables of clothing configuration and time, were used to analyze the dependent variables of T_{re}, ΔT_{re}, $\bar{T}_{sk}$, and HR. These data were analyzed at 100 minutes for SIPE 0 and MOPP 0; 93 minutes for SIPE 1 and MOPP 1; 55 minutes for SIPE 4 NC, SIPE 4 MCC and MOPP 4 at 30.0°C; and 89 minutes for SIPE 4 NC, and MOPP 4 at 18.5°C. These

MOPP 4 at 30.0°C; and 89 minutes for SIPE 4 NC, and MOPP 4 at 18.5°C. These were the final times with data on sufficient subjects to conduct data analysis. Endurance time (ET), M_{sw}, E_{tot} and S were analyzed between configurations using a one way analysis of variance. Analysis of covariance was used to determine whether differences in metabolic rate created by the varying loads in the MOPP 4 and SIPE 4 configurations affected the dependent variables. When significant differences were found, Tukey's test of critical difference was used for post hoc analysis. All differences were tested at the $p<0.05$ level. Data are reported as the mean (± standard deviation).

Minimizing Risks to the Volunteers

The procedures in this study fall within the restrictions and safety limitations of the USARIEM Type Protocol on Human Research Studies (1 June 1990). Volunteers were medically screened (history and examination) before participation in this study to exclude those for whom the combined stress of exercise and hyperthermia posed a greater hazard than for normal healthy persons. A medical officer was present or readily available during testing of these volunteers. Experimental testing was performed at the Natick Tropic Chamber Facility. All limits of thermal exposure specified in the Type Protocol were adhered to: testing was discontinued if T_{re} reached 39.5°C during exercise, or if HR reached or exceeded 90% of the measured (measured for n=7; estimated for n=1) maximum heart rate for five continuous minutes. The volunteers were also removed from thermal stress at their request, or at the discretion of the medical monitor or the investigator.

RESULTS/DISCUSSION

The initial portion of the results/discussion section will be concerned entirely with the results of the 100 minute tests. At the end, is a discussion on the observed results of the three volunteers who completed the 4-hour test in SIPE with MCC.

Analyses were conducted and results will be reported on the uniforms in matching NBC protective level and environment. First will be results of SIPE 0 versus MOPP 0 in the warm environment; then SIPE 1 versus MOPP 1 in the warm environment, then SIPE NC versus SIPE 4 MCC versus MOPP 4 in the warm environment; finally SIPE 4 NC versus MOPP 4 in the cool environment. Table 2 contains mean ± standard deviation data on all variables measured in all configurations.

SIPE 0 VS MOPP 0

The metabolic rate for SIPE 0 (451±27 W) was less than for MOPP 0 (462±32 W). All eight volunteers completed the 100-minute test in both uniforms. Figures 1-7 graphically represent the analyzed data for the SIPE 0 vs MOPP 0 tests. There were no differences between the uniforms for any of the physiological data. At the completion of exercise, the volunteers had mean T_{re} in both uniforms below 37.9°C and mean HR below 125 b•min^{-1}. Regression analyses of the core temperature changes over time indicate a possible stay time of 208 minutes in SIPE 0 and 195 minutes in MOPP 0 before soldiers would reach a T_{re} of 39.5°C.

Table 2. Means (± standard deviations) for average metabolic rate and thermoregulatory variables measured at the following times: MOPP 0 vs SIPE 0, 100 min; MOPP 1 vs SIPE 1, 93 min; MOPP 4 vs SIPE 4 NC vs SIPE 4 MCC, 55 min; MOPP 4 COOL vs SIPE 4 NC COOL 89 min.

	MOPP 0	SIPE 0	MOPP 1	SIPE 1	MOPP 4	SIPE 4 NC	SIPE 4 MCC	MOPP 4 COOL	SIPE 4 NC COOL
METABOLISM (W)	462 ±32	*451 ±27	485 ±29	490 ±30	567 ±17	*515 ±35	556 ±26	515 ±15	*485 ±9
ET (MIN)	100 ±0	100 ±0	99 ±2	100 ±0	*86 ±9	**64 ±11	*93 ±7	98 ±5	97 ±4
T_{RE} (°C)	37.9 ±0.2	37.9 ±0.3	38.1 ±0.3	38.2 ±0.4	38.5 ±0.4	38.4 ±0.3	*38.0 ±0.3	37.7 ±0.1	37.6 ±0.2
ΔT_{RE} (°C)	1.1 ±0.1	1.0 ±0.3	1.4 ±0.3	1.3 ±0.3	1.6 ±0.3	1.6 ±0.3	*1.2 ±0.3	1.0 ±0.2	0.9 ±0.3
$\bar{T}_{SK}$ (°C)	34.4 ±0.5	34.5 ±0.7	35.7 ±0.4	35.5 ±0.4	36.6 ±0.6	36.8 ±0.4	*35.7 ±0.7	34.0 ±0.8	33.8 ±0.3
S $W \cdot M^{-2}$	22 ±4	23 ±6	32 ±7	30 ±6	68 ±13	66 ±12	*44 ±11	24 ±6	21 ±7
HR $(B \cdot MIN^{-1})$	123 ±12	118 ±11	135 ±14	136 ±14	161 ±19	159 ±15	*145 ±12	130 ±18	126 ±10
M_{SW} $(G \cdot M^{-2} \cdot H^{-1})$	456 ±58	421 ±70	615 ±67	611 ±66	758 ±114	820 ±88	669 *±81	413 ±60	405 ±58
E_{TOT} $(W \cdot M^{-2})$	166 ±38	176 ±17	181 ±9	185 ±17	167 ±20	143 ±25	*201 ±17	149 ±66	112 ±7

* MEAN CORRECTED FOR COVARIANCE WITH METABOLIC RATE

* DIFFERENT FROM EQUIVALENT MOPP CONFIGURATION IN THE SAME ENVIRONMENTAL CONDITIONS

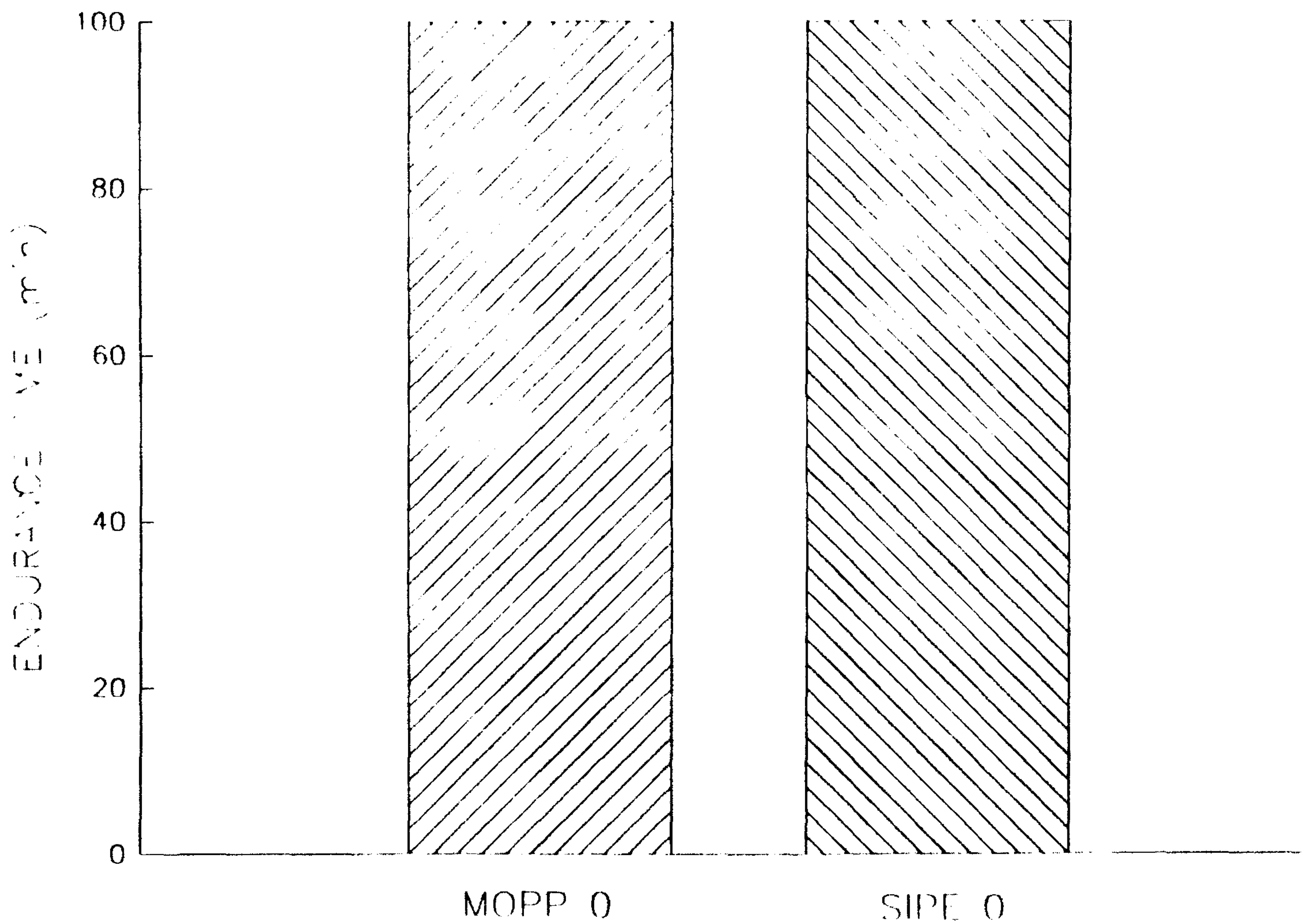

Figure 1. The mean endurance time of subjects walking continuously on a treadmill at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 0 or the SIPE equivalent. Maximum experimental time of 100 minutes.

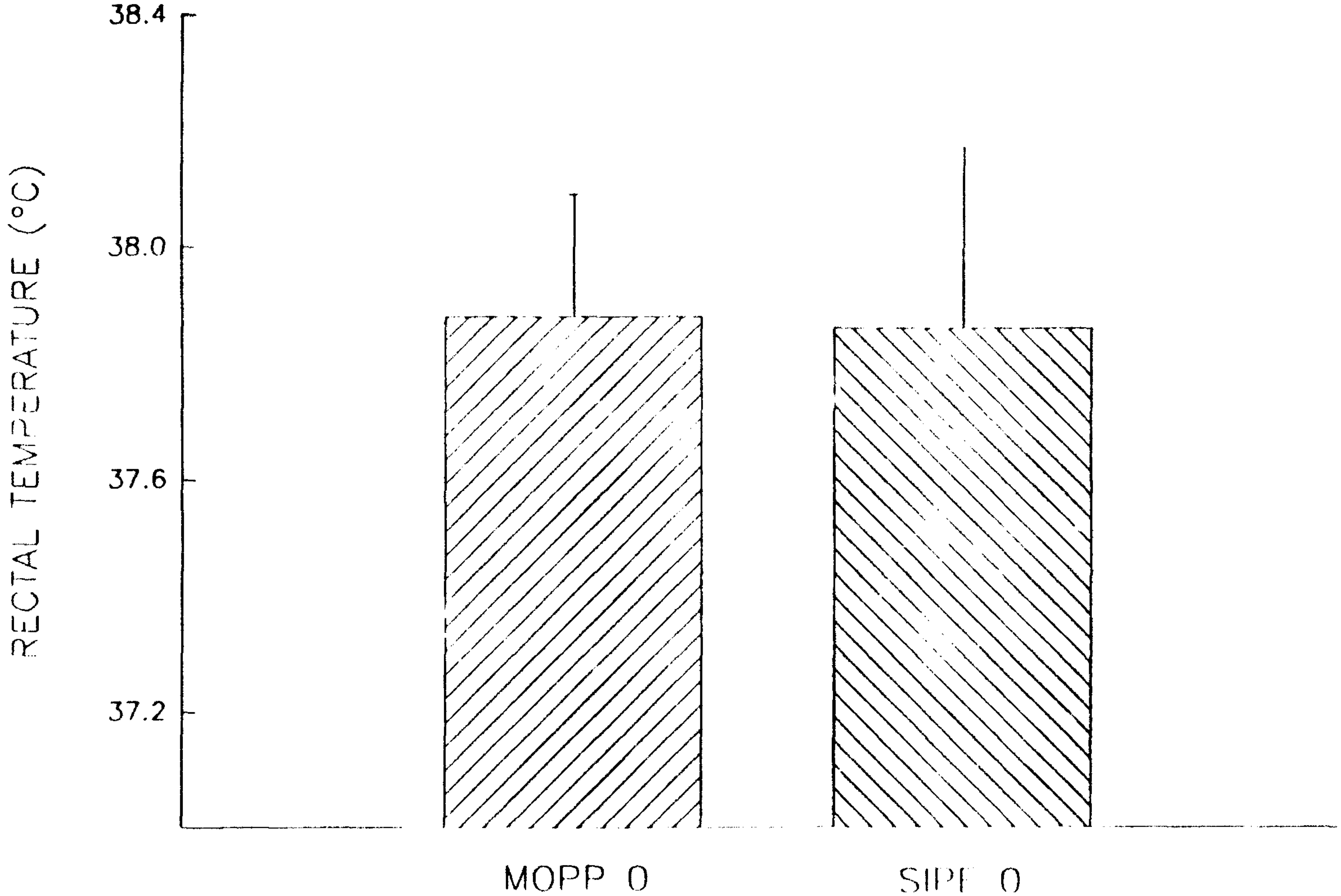

Figure 2. The mean ±SD rectal temperature of the subjects after 100 min of continuous treadmill walking at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 0 or the SIPE equivalent

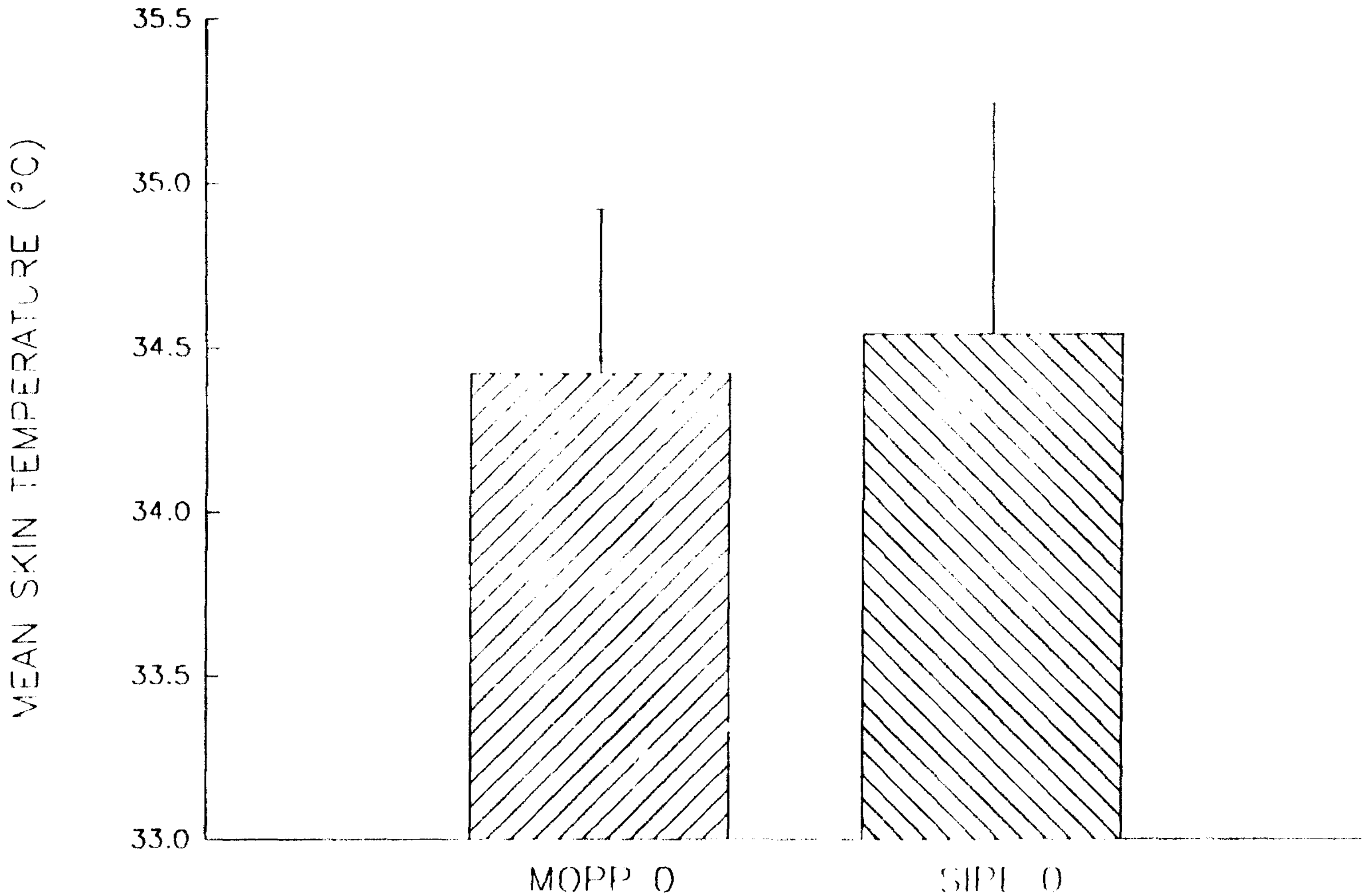

Figure 3. The mean ±SD four point mean skin temperature of the subjects after 100 min of continuous treadmill walking at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 0 or the SIPE equivalent.

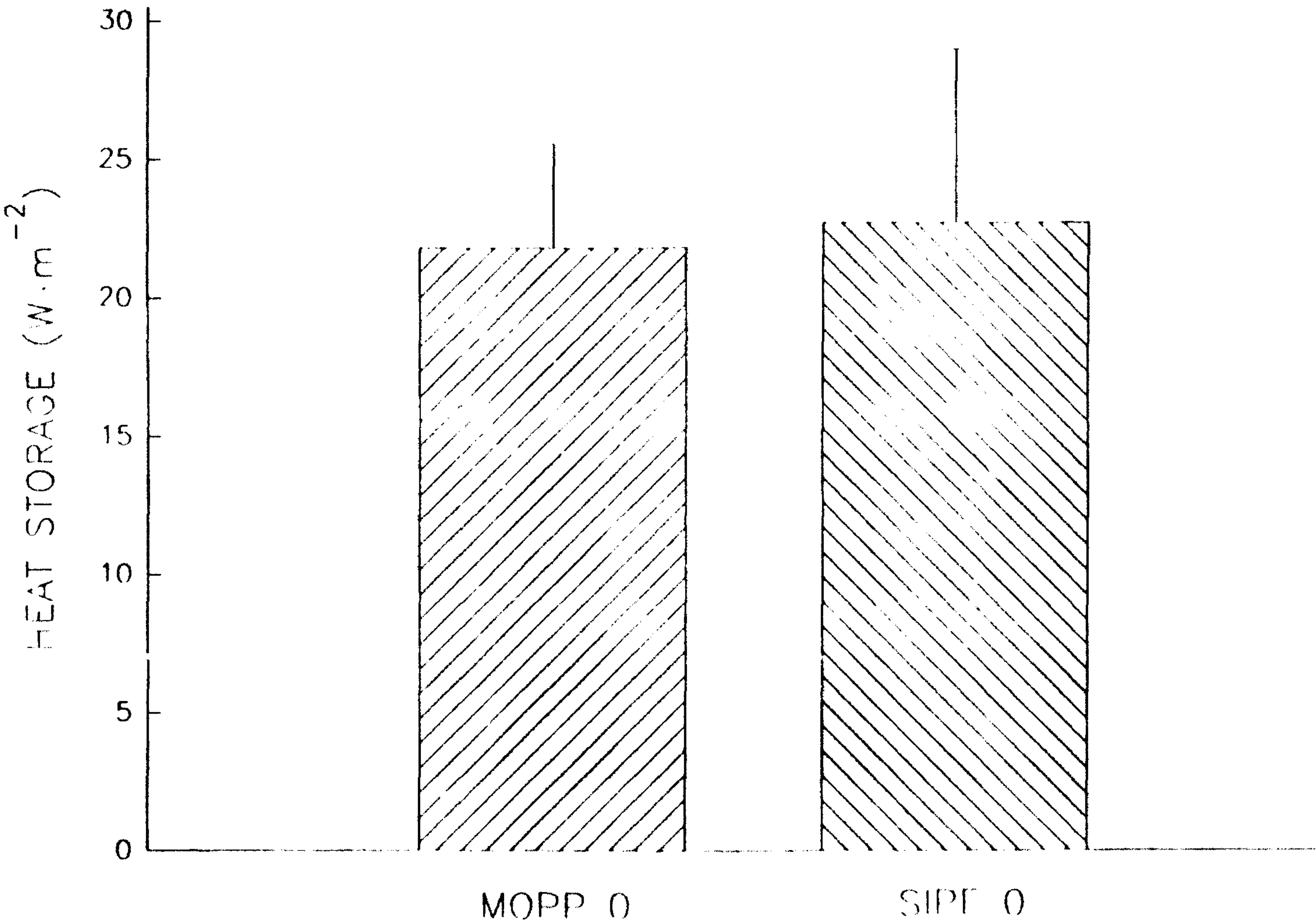

Figure 4. The mean ±SD calculated heat storage of the subjects after 100 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 0 or the SIPE equivalent.

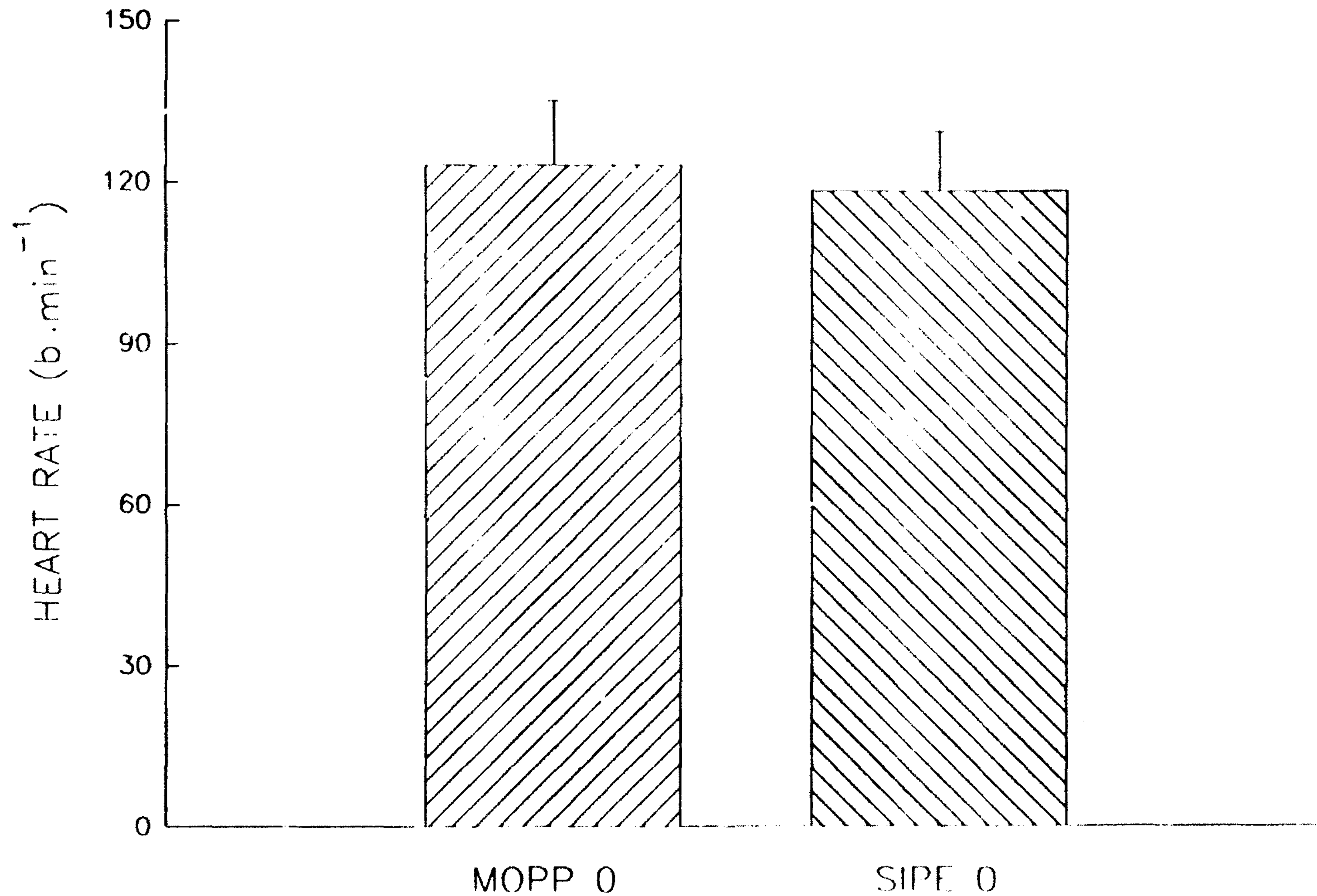

Figure 5. The mean ±SD heart rate of the subjects after 100 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 0 or the SIPE equivalent

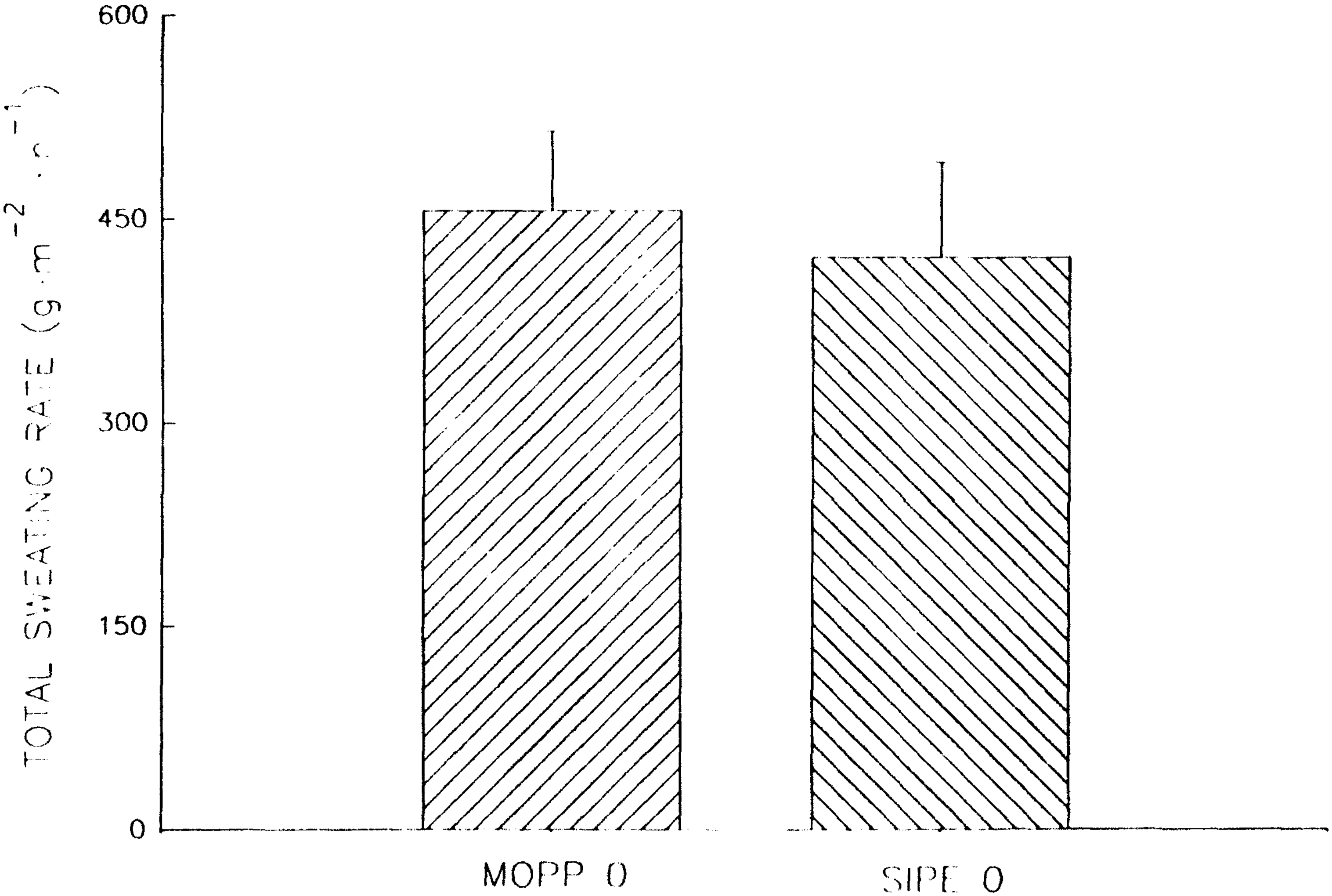

Figure 6. The mean ±SD total sweating rate of the subjects after 100 min of continuous treadmill walking at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 0 or the SIPE equivalent.

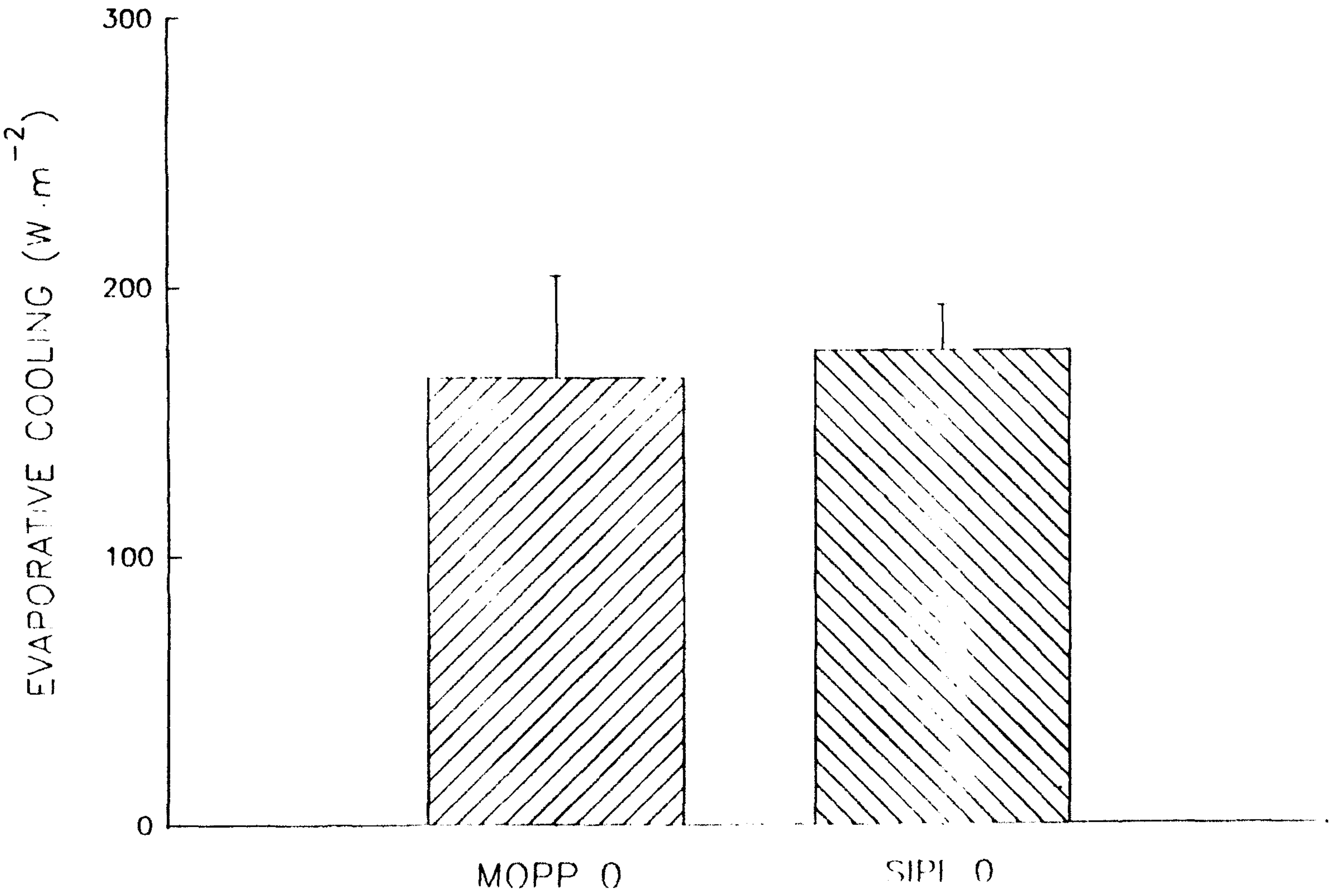

Figure 7. The mean ±SD evaporative cooling of the subjects after 100 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 0 or the SIPI equivalent.

SIPE 1 VS MOPP 1

The metabolic rate for SIPE 1 (490±30 W) was not different from MOPP 1 (485±29 W). Seven of eight volunteers completed the 100 minute test in both uniforms. The one who did not complete the test was removed at the investigator's discretion at 93 minutes while wearing MOPP 1 because his rectal thermistor probe was slipping and could not be adjusted prior to the end of the 100 minute test. Figures 8-14 graphically represent the analyzed data for the SIPE 1 vs MOPP 1 tests. There were no differences between the uniforms for any of the physiological data. The volunteers' mean T_{re} was no greater than 38.2°C in either uniform in the analysis performed at 93 minutes. Regression analyses of the core temperature changes over time indicate a possible stay time of 156 minutes in SIPE 1 and 159 minutes in MOPP 1 before soldiers would reach a T_{re} of 39.5°C.

SIPE 4 NC VS SIPE MCC VS MOPP 4

The metabolic rate in SIPE 4 NC (515±35 W) was significantly less than the metabolic rates in both SIPE 4 MCC (556±26 W) and MOPP 4 (567±17 W) which were not different from each other. An ANCOVA using the metabolic rates with the dependent variables, affected only ET, resulting in adjusted mean times. Physiological variables were not affected by the different metabolic rates. Figures 15-21 graphically represent the analyzed data for the SIPE 4 NC vs SIPE 4 MCC vs MOPP 4 tests. Figure 15 shows endurance time means without adjustment for the covariate. Figure 15a shows the endurance times with means adjusted by the ANCOVA. While the ANCOVA adjusted the means, the endurance times in this test were already skewed by a poorly designed hose arrangement between the chemical protective mask and the C2 canister in the SIPE 4 NC configuration. This hose doubled the resistance to breathing for subjects in this configuration relative to the MOPP 4 configuration. This increased resistance, and not heat stress, was the cause of termination of the test in 5 of the 6 volunteers performing the SIPE 4 NC test. Because the metabolic rate was significantly less in SIPE 4 NC, it would have been logical to expect the endurance times of the volunteers in this uniform configuration to be longer than in the other two configurations. Instead as Figure 15 shows the uncorrected mean endurance times were nearly identical so that when the lower metabolic rate was taken into

consideration by the use of ANCOVA, the endurance time in SIPE 4 NC was significantly less than in the other two configurations.

At 55 minutes ΔT_{re} in SIPE 4 MCC was 1.2±0.3°C which was significantly less than both SIPE 4 NC (1.6±0.3°C) and MOPP 4 (1.6±0.3°C). $\bar{T}_{sk}$ in SIPE 4 MCC (35.7±0.7°C) was significantly less than both SIPE 4 NC (36.8±0.4°C) and MOPP 4 (36.6±0.6°C). The rate of heat storage for volunteers in SIPE 4 MCC (44±11 $W \cdot m^{-2}$) was significantly less than in both SIPE 4 NC (66±12 $W \cdot m^{-2}$) and MOPP 4 (68±13 $W \cdot m^{-2}$). HR in SIPE 4 MCC (145±12 $b \cdot min^{-1}$) was significantly less than in both SIPE 4 NC (159±15 $b \cdot min^{-1}$) and MOPP 4 (161±19 $b \cdot min^{-1}$). M_{sw} in SIPE 4 MCC (669±81 $g \cdot m^{-2} \cdot h^{-1}$) was significantly less than in SIPE 4 NC (820±88 $g \cdot m^{-2} \cdot h^{-1}$), but not different from MOPP 4 (758±114 $g \cdot m^{-2} \cdot h^{-1}$). $E_{t\alpha}$ in SIPE 4 MCC (201±17 $W \cdot m^{-2}$) was significantly greater than both SIPE 4 NC (144±25 $W \cdot m^{-2}$) and MOPP 4 (164±20 $W \cdot m^{-2}$). Regression analyses of the core temperature changes over time indicate a possible stay time of 91 minutes in SIPE 4 NC, 130 minutes in SIPE 4 MCC, and 88 minutes in MOPP 4 before soldiers would reach a T_{re} of 39.5°C.

While the MCC unit added approximately 10 kg of weight to the volunteers relative to either SIPE 4 NC or MOPP 4, the ambient air provided by the system reduced heat storage. Lowered chest skin temperatures and total sweating rates, coupled with increased evaporative sweating reduced the rate of heat storage, and decreased heart rate. These physiological differences resulted in improved performance, as indicated by the fact that three of the volunteers completed the 100 minutes of exercise in the SIPE 4 MCC configuration while only one volunteer completed the 100 minutes in either SIPE 4 NC or MOPP 4.

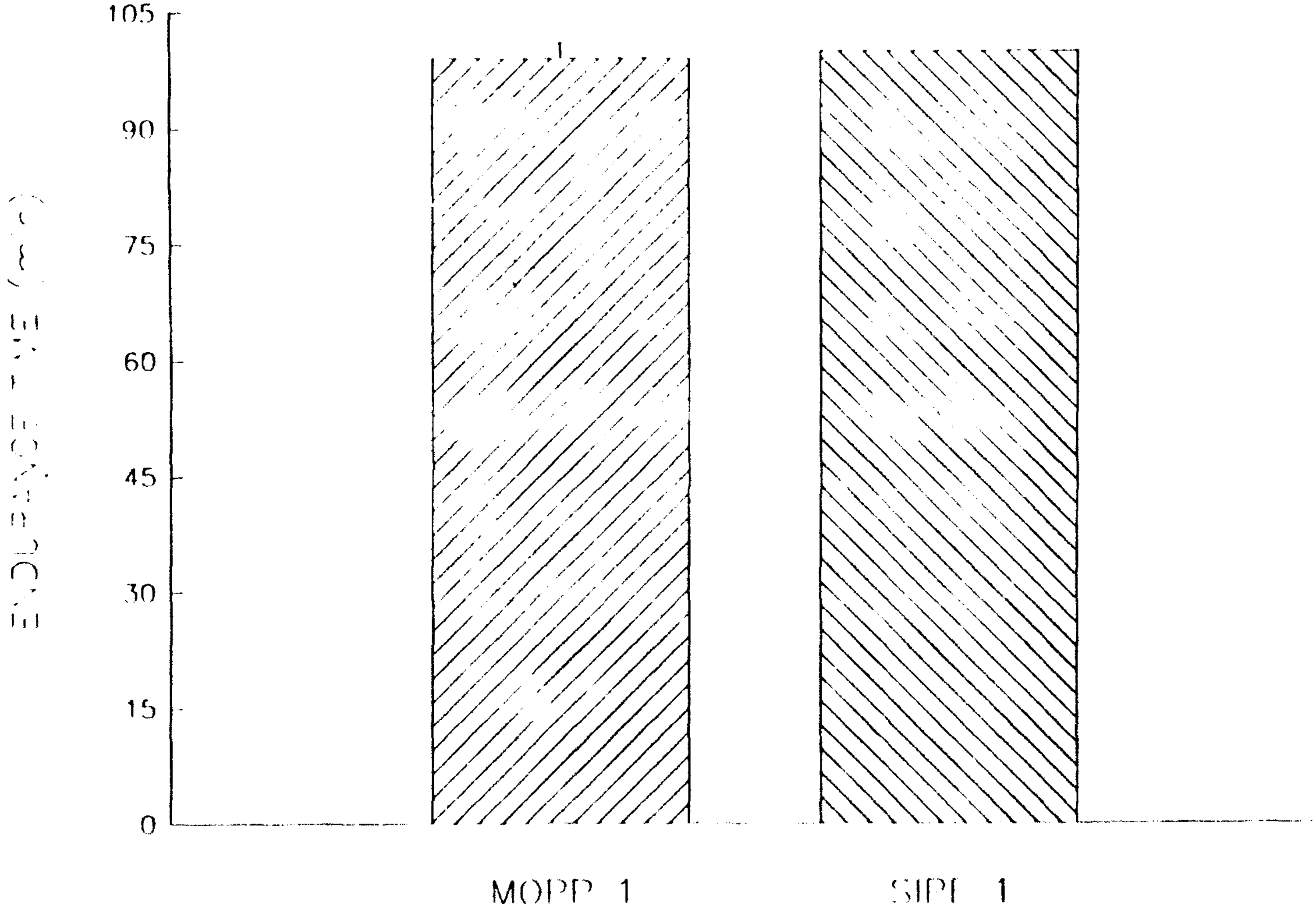

Figure 8. The mean ±SD endurance time of subjects walking continuously on a treadmill at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 1 or the SIPE equivalent. Maximum experimental time of 100 minutes.

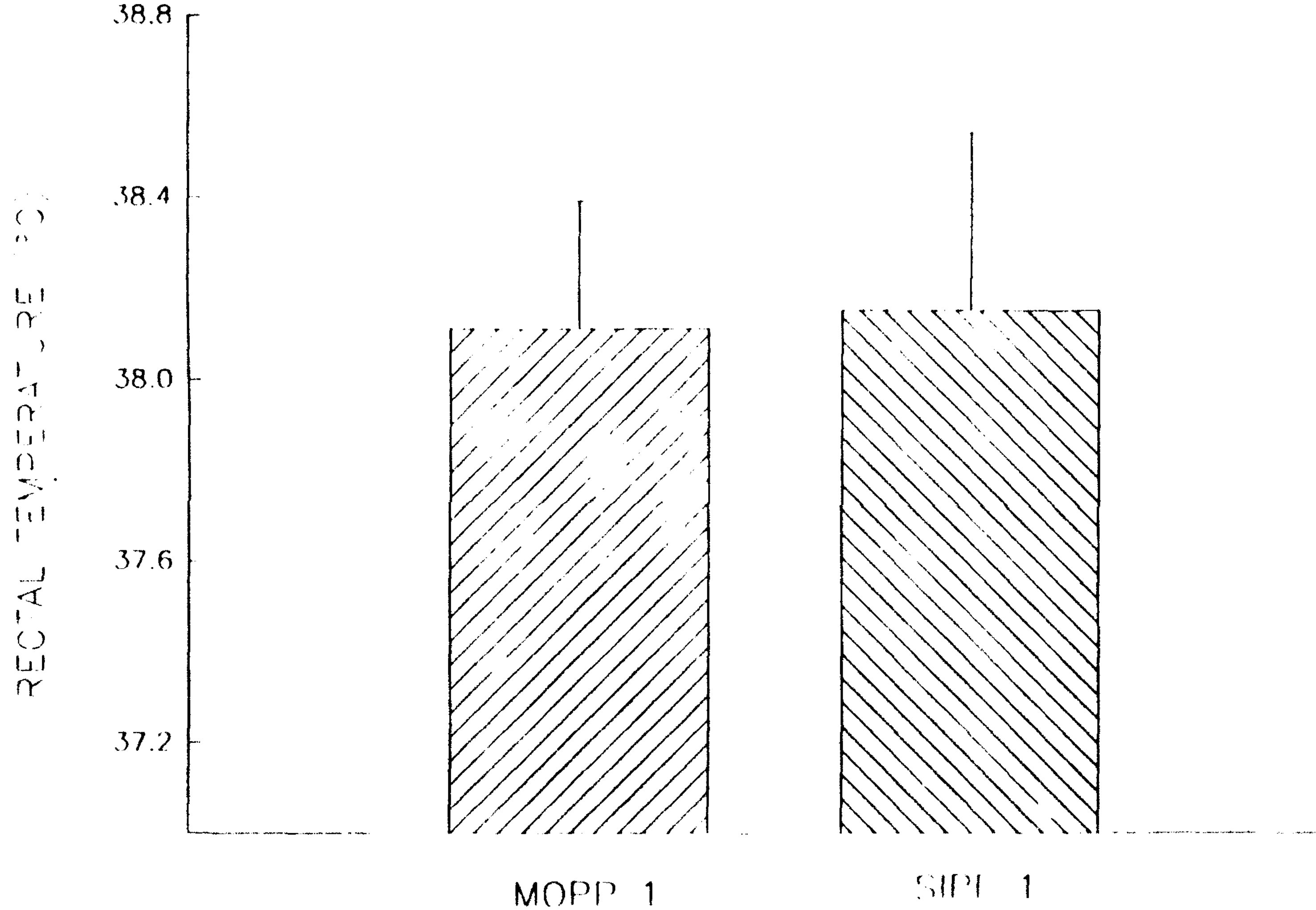

Figure 9. The mean ±SD rectal temperature of the subjects after 93 min of continuous treadmill walking at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 1 or the SIPE equivalent.

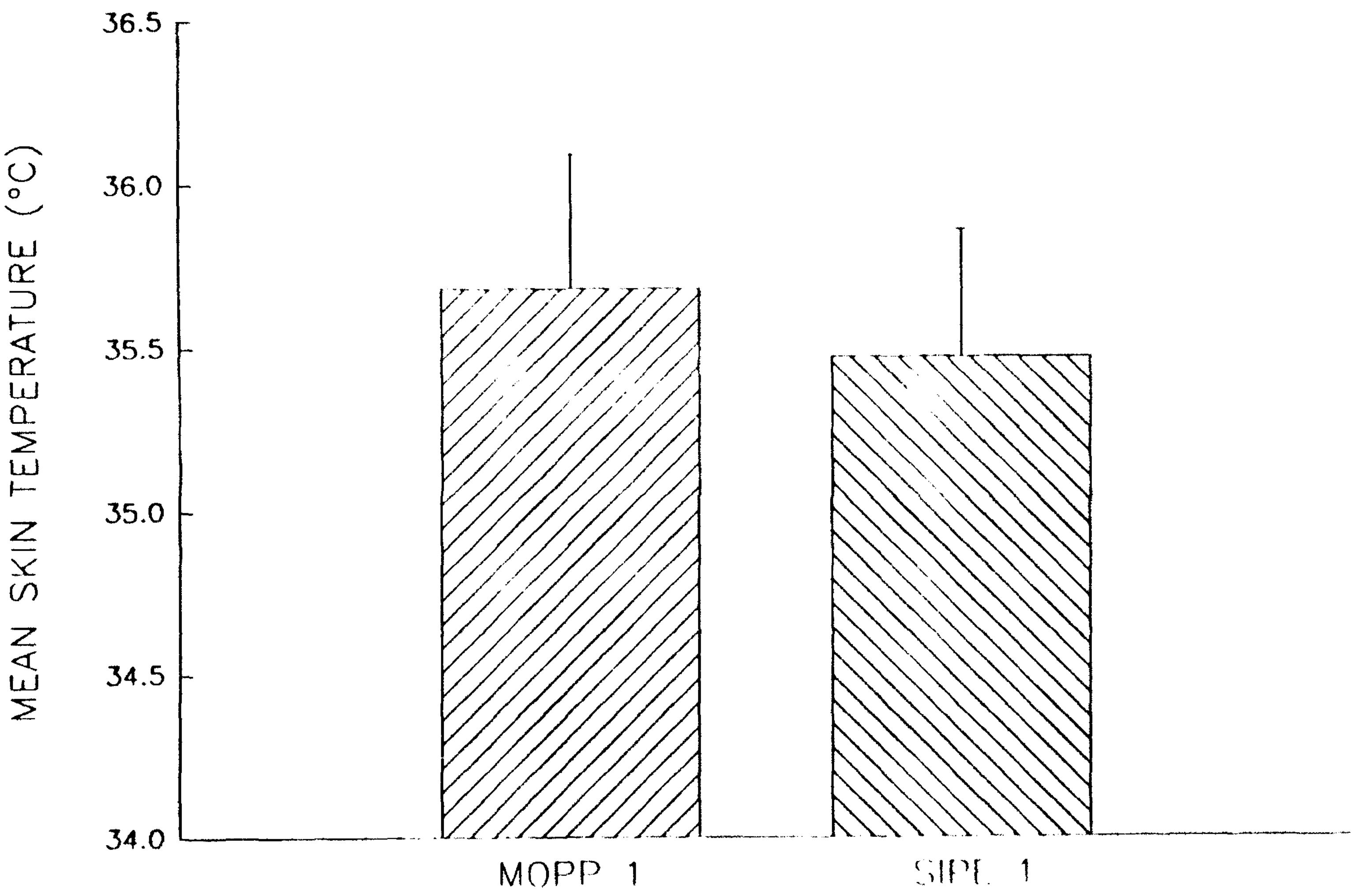

Figure 10. The mean ±SD four point mean skin temperature of the subjects after 93 min of continuous treadmill walking at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 1 or the SIPE equivalent.

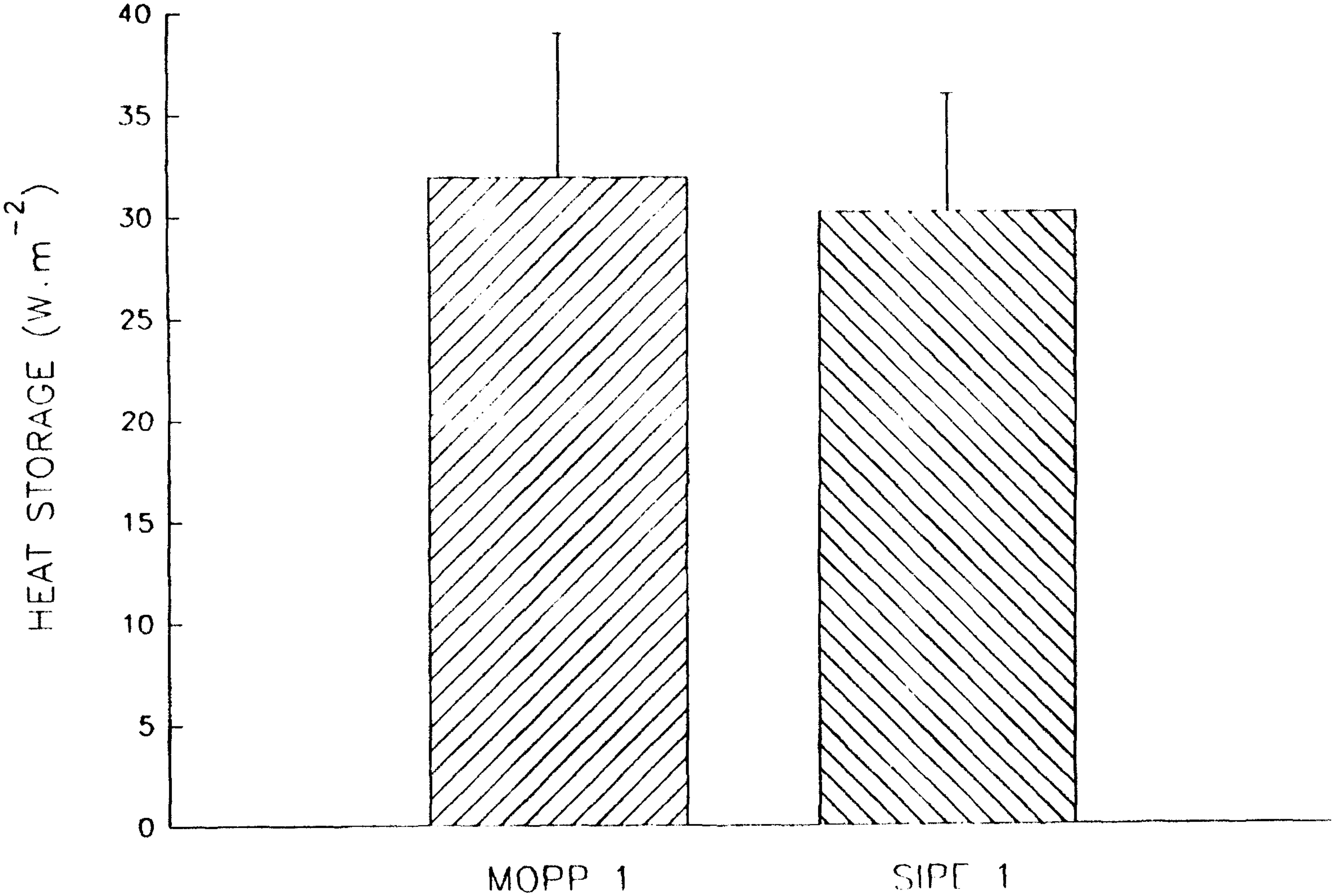

Figure 11. The mean ±SD calculated heat storage of the subjects after up to 100 min of continuous treadmill walking (range 93–100 min) at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 1 or the SIPE equivalent.

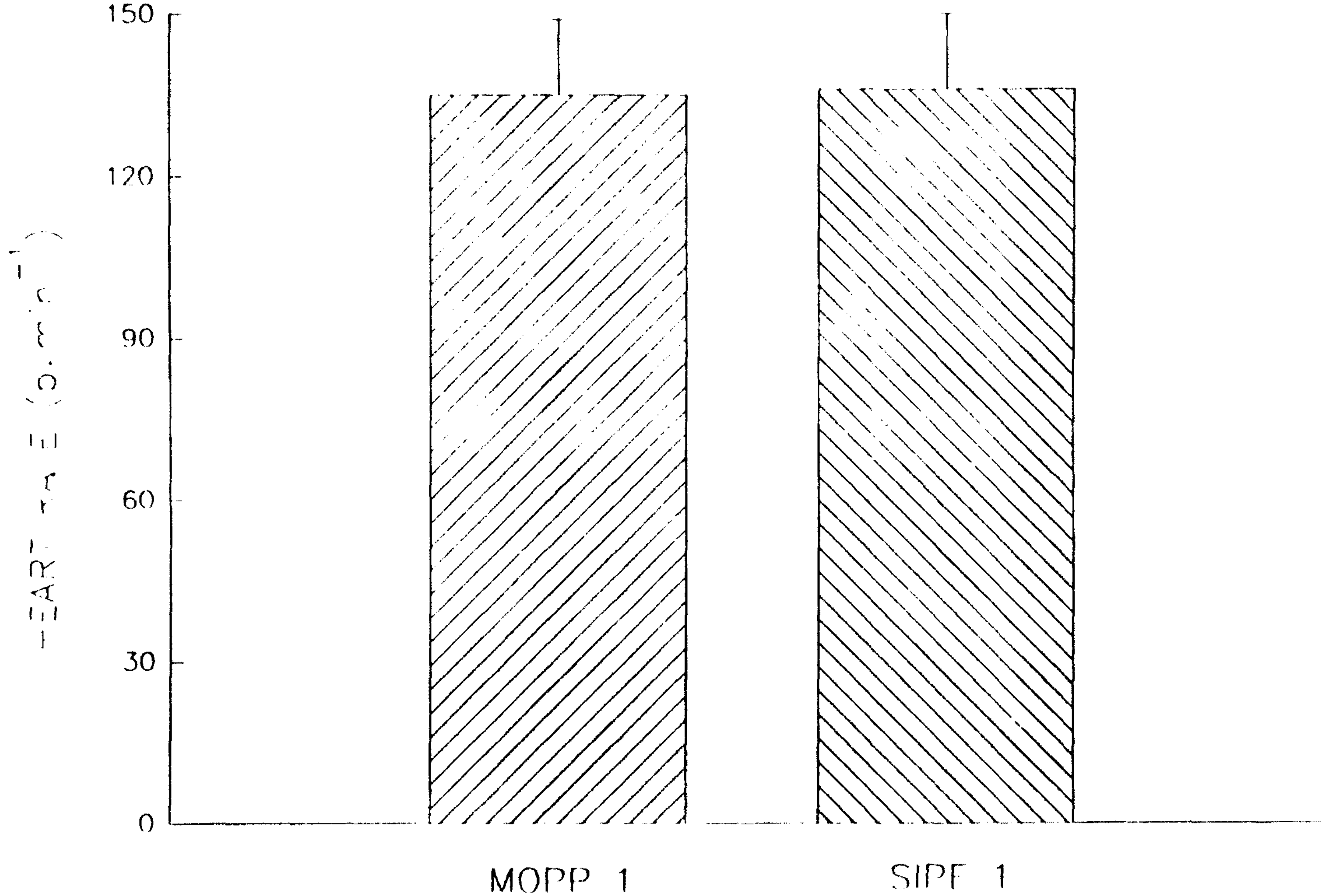

Figure 12. The mean $\pm$SD heart rate of the subjects after 90 minutes of continuous treadmill walking at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 1 or the SIPE equivalent.

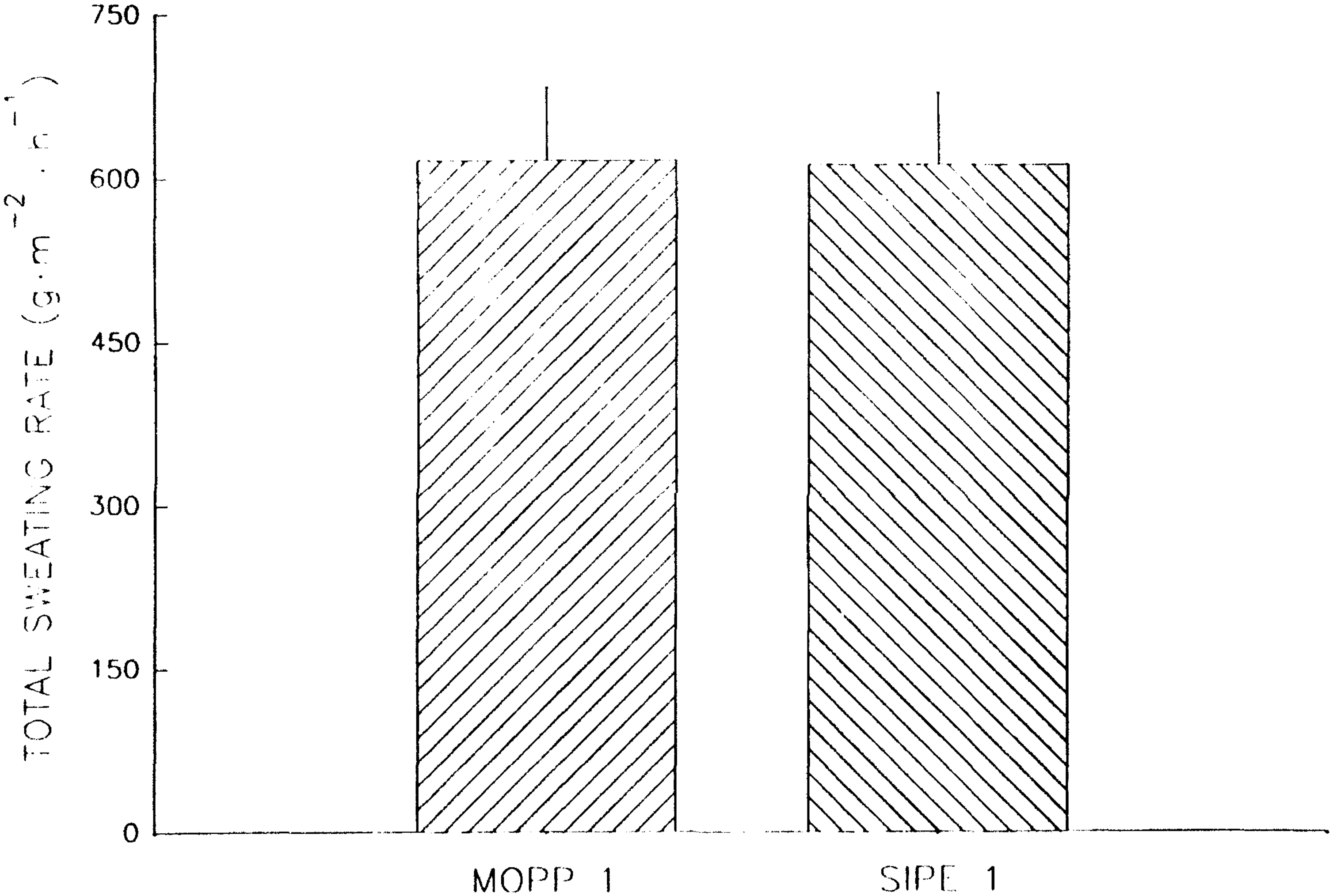

Figure 13. The mean ±SD total sweating rate of the subjects after up to 100 min of continuous treadmill walking (range 93–100 min) at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 1 or the SIPE equivalent.

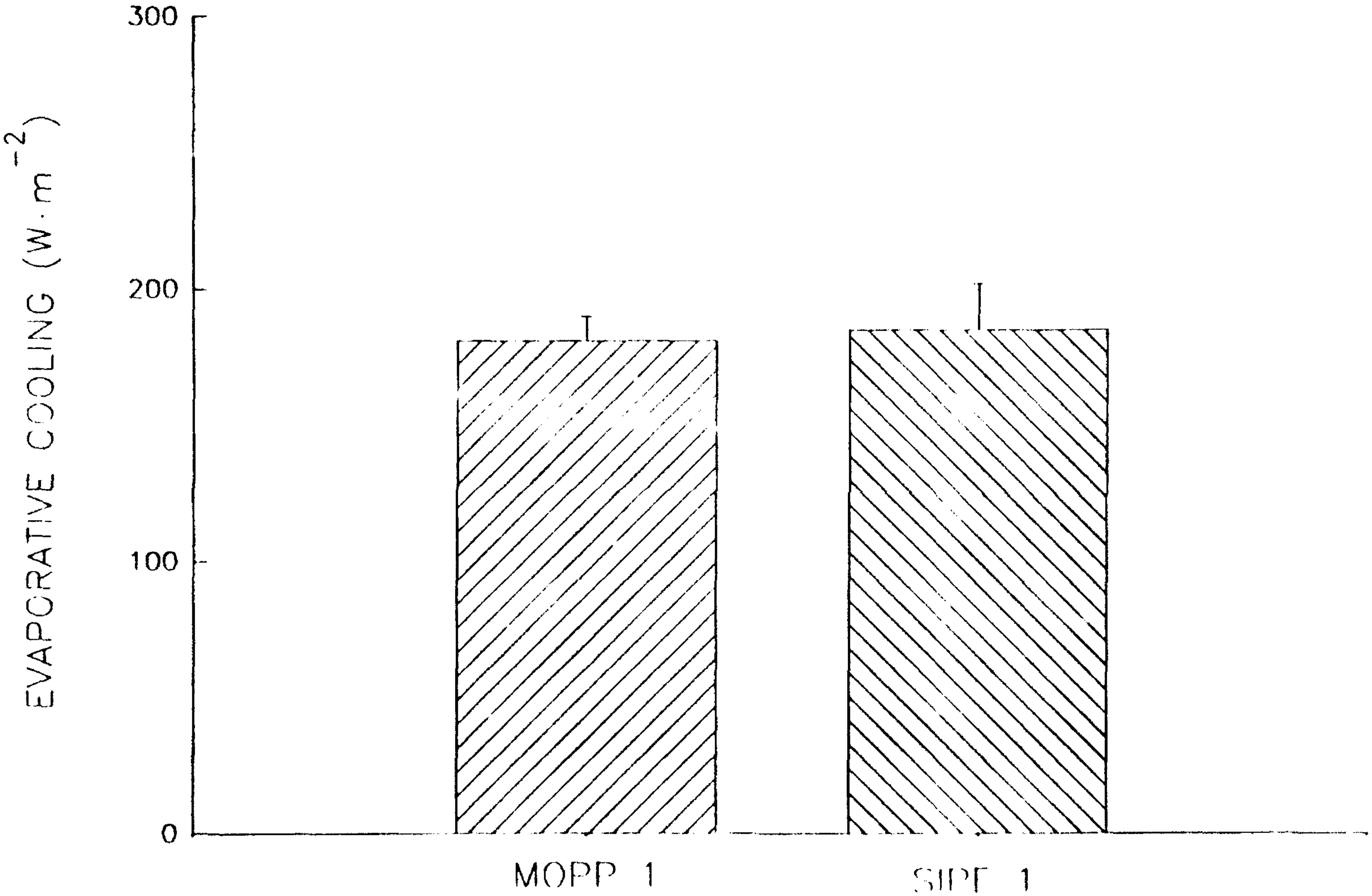

Figure 14. The mean ±SD evaporative cooling of the subjects after up to 100 min of continuous treadmill walking (range 93–100 min) at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing either MOPP 1 or the SIPE equivalent.

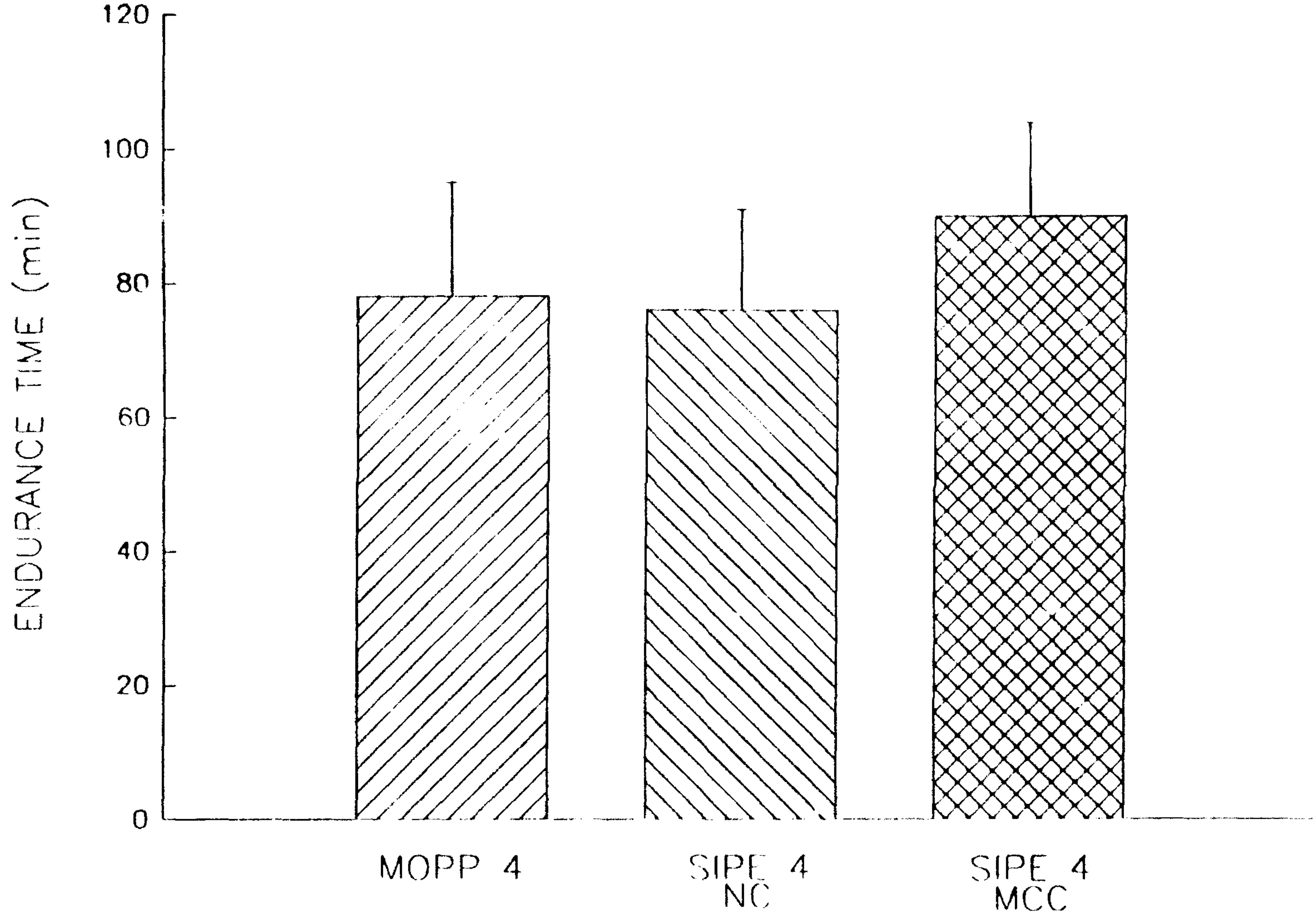

Figure 15. The mean ±SD endurance time of the subjects walking continuously on a treadmill at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). Maximum experimental time of 100 min.

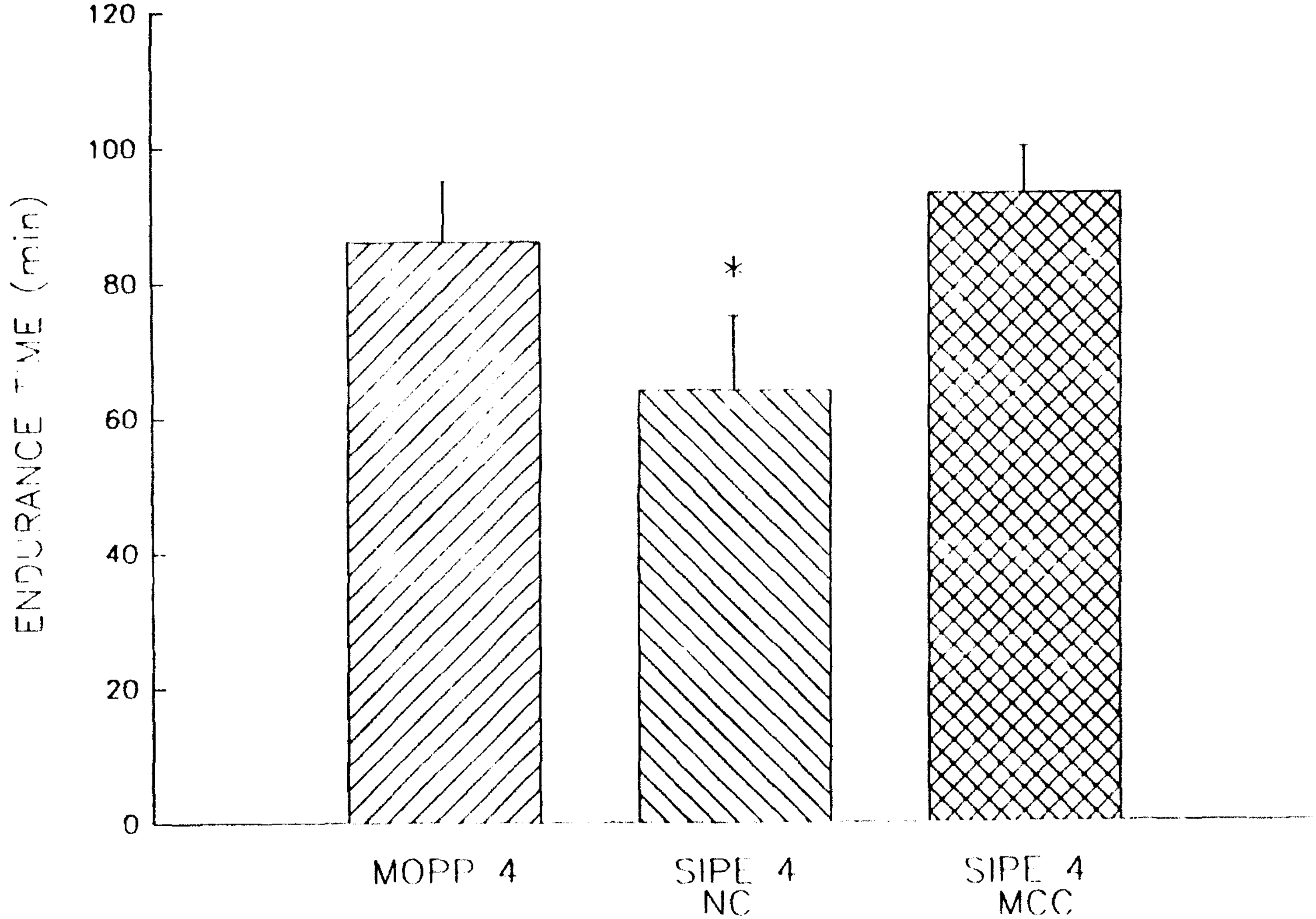

Figure 15a. The mean ±SD endurance time (corrected for weight differences with ANCOVA) of the subjects walking continuously on a treadmill at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). Maximum experimental time of 100 min. * Less than MOPP 4 and SIPE 4 MCC

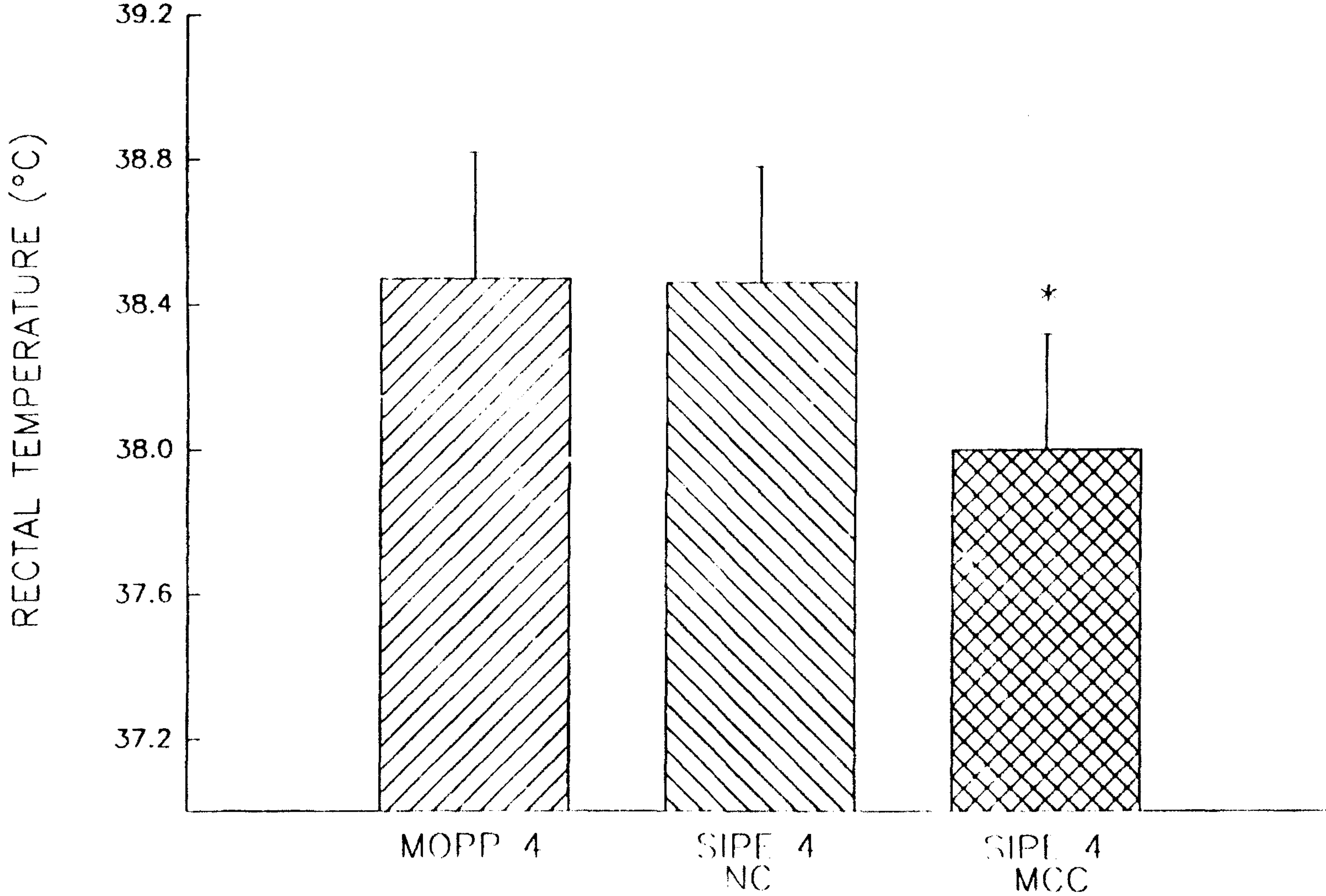

Figure 16. The mean ±SD rectal temperature of the subjects after 55 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). * Less than MOPP 4

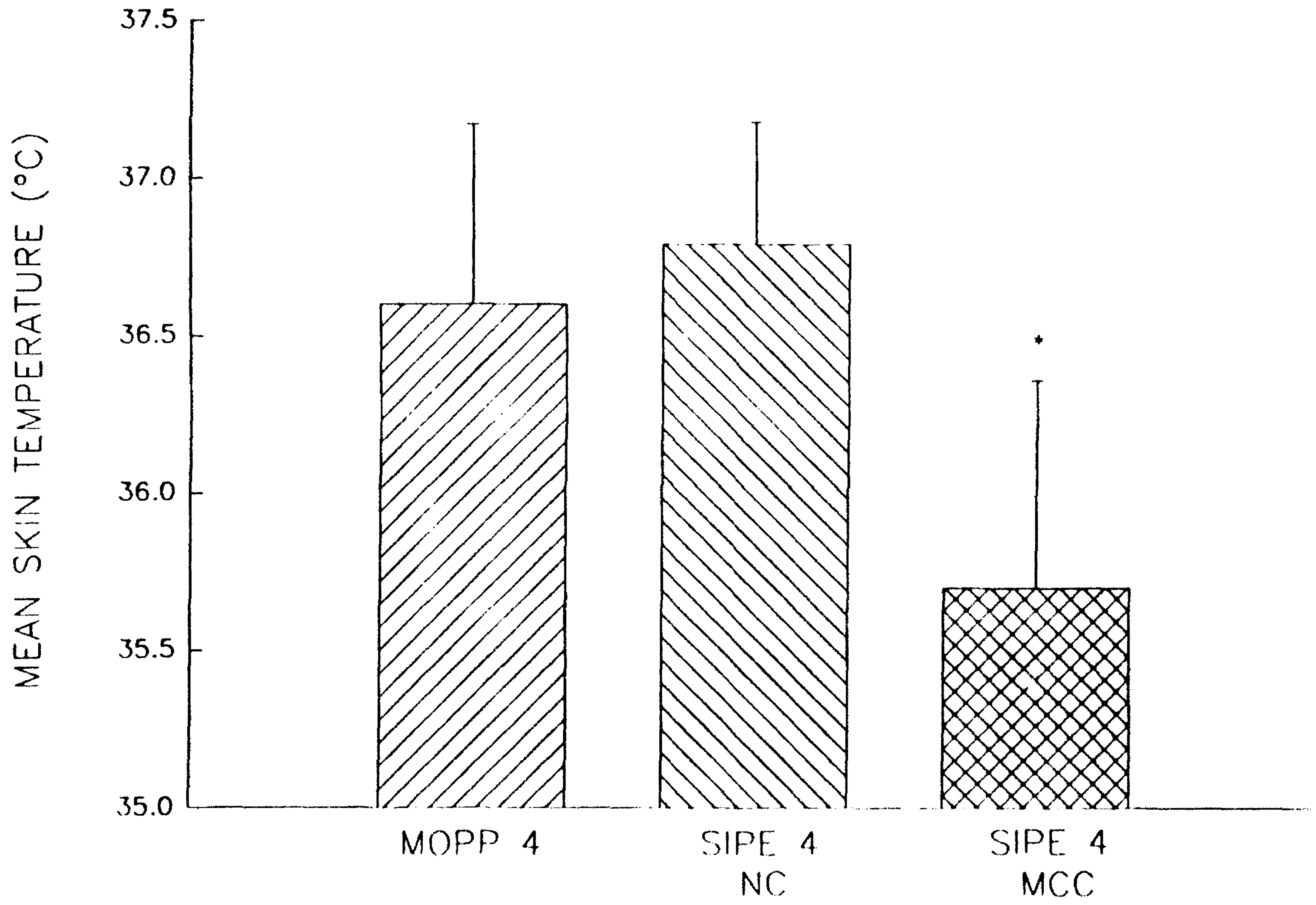

Figure 17. The mean ±SD four point mean skin temperature of the subjects after 55 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). * Less than MOPP 4 and SIPE 4 NC.

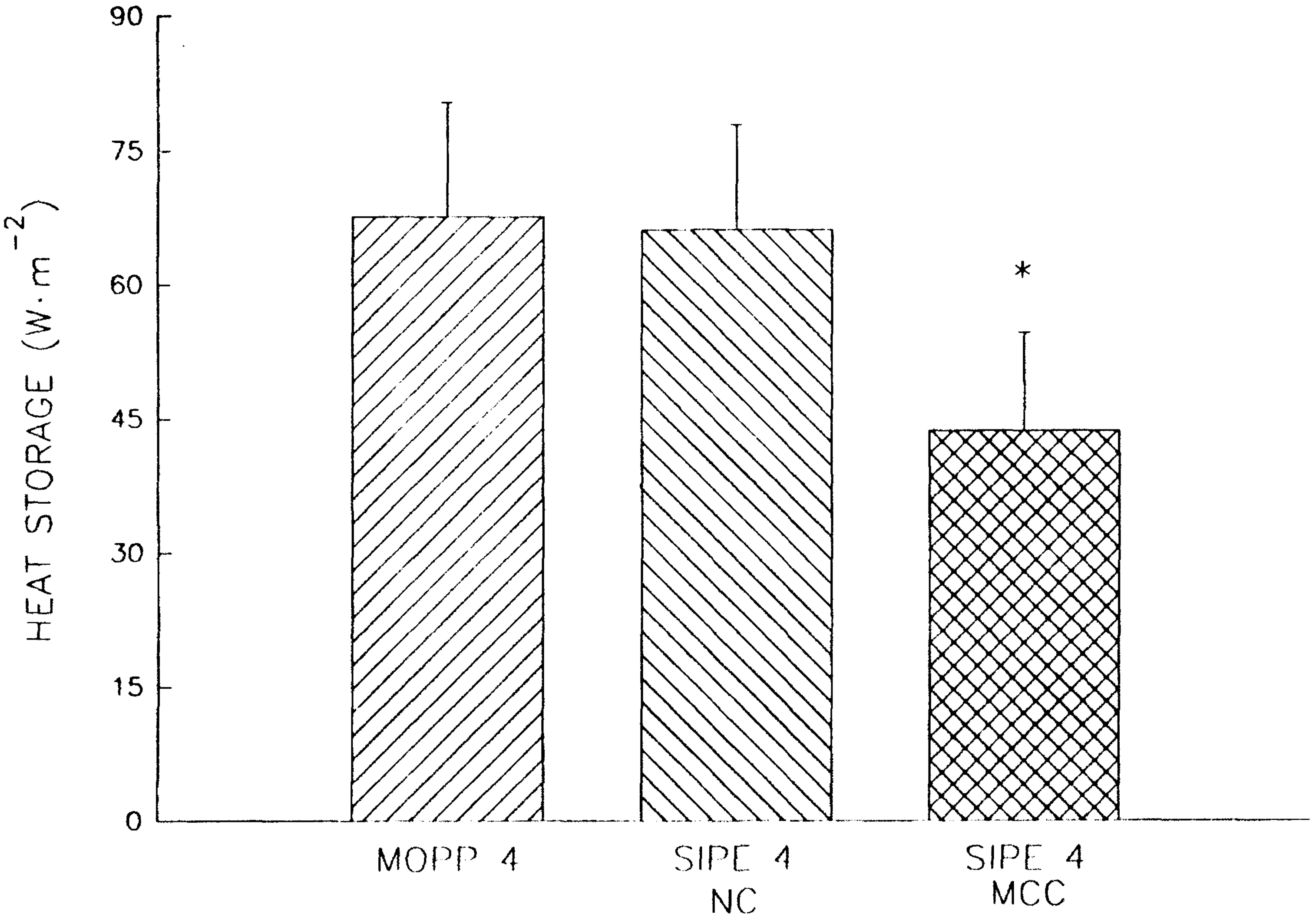

Figure 18. The mean ±SD calculated heat storage of the subjects after up to 100 min of continuous treadmill walking (range 55–100 min) at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). * Less than MOPP 4 and SIPE 4 NC.

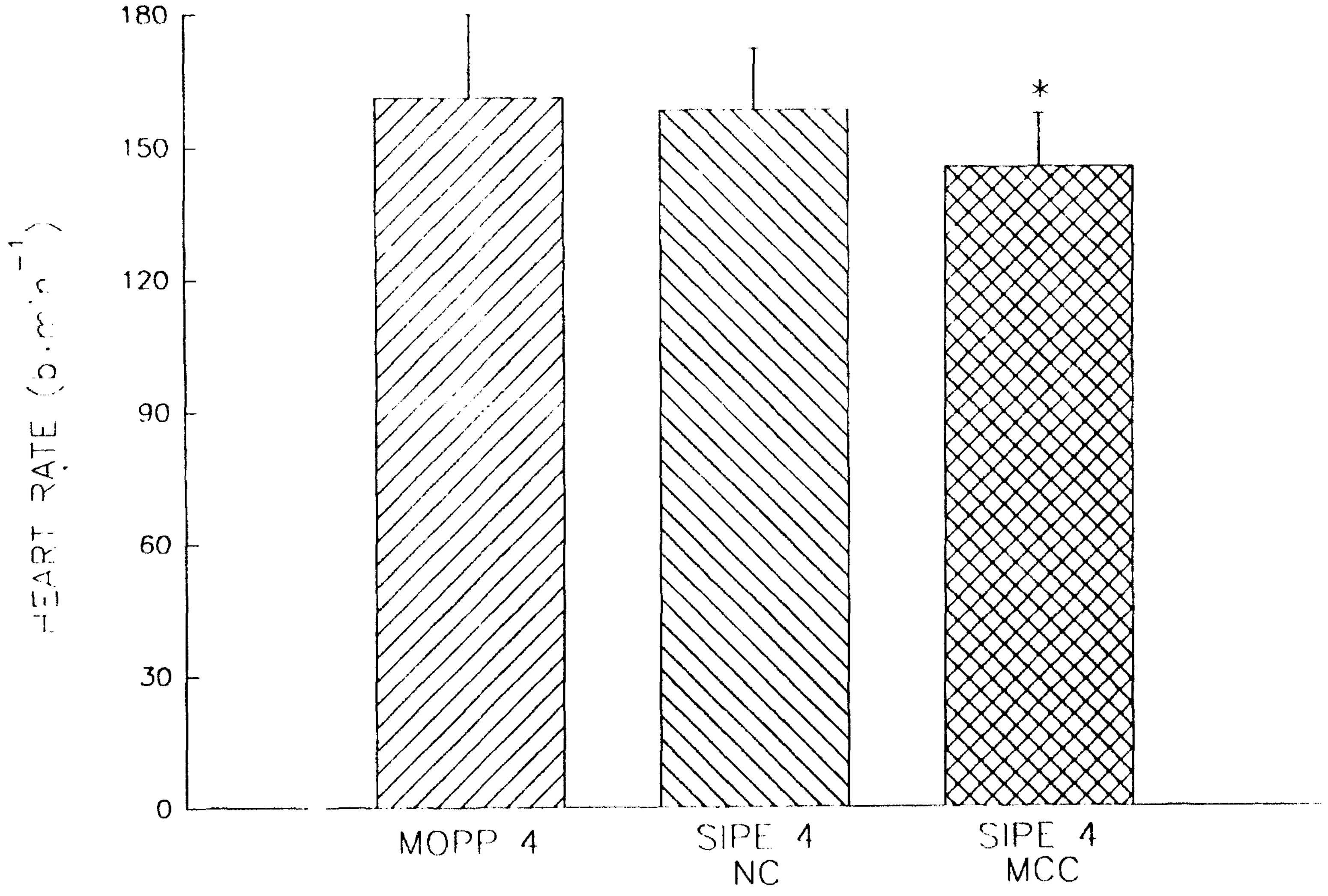

Figure 19. The mean ±SD heart rate of the subjects after 50 min of continuous treadmill walking at 1.34 $m \cdot sec^{-1}$, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). * Less than MOPP 4 and SIPE 4 NC.

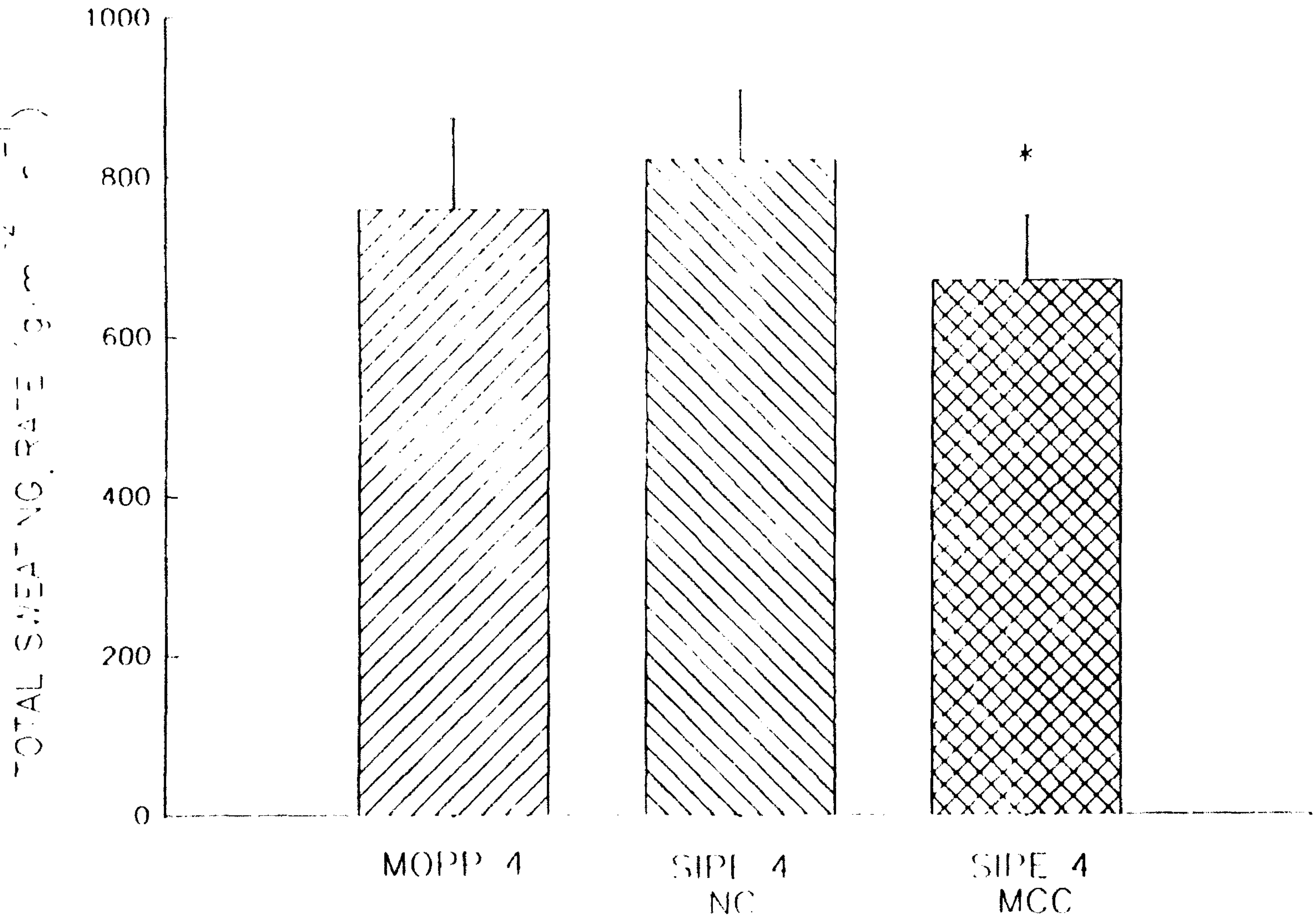

Figure 20. The mean ±SD total sweating rate of the subjects after up to 100 min of continuous treadmill walking (range 55–100 min) at 1.34 m·sec⁻¹, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). * Less than SIPE 4 NC.

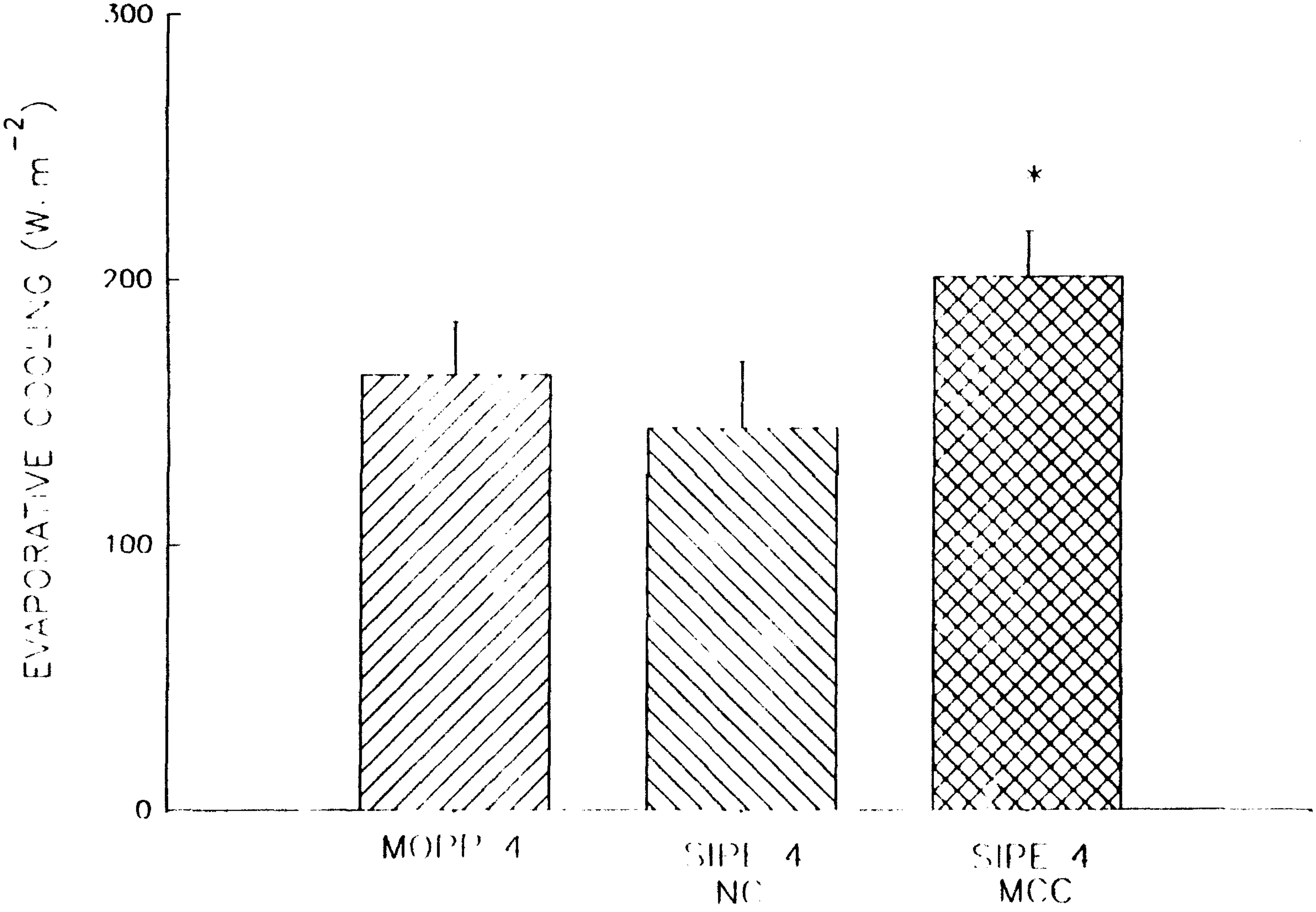

Figure 21. The mean ±SD evaporative cooling of the subjects after up to 100 min of continuous treadmill walking (range 55–100 min) at 1.34 m·sec^{-1}, 3% grade in a 30.0°C, 50% rh environment while wearing MOPP 4, or the SIPE equivalent with either no cooling (NC) or ambient air microclimate cooling (MCC). * Greater than MOPP 4 and SIPE 4 NC.

SIPE 4 NC VS MOPP 4 (18.5°C ENVIRONMENT)

The metabolic rate in SIPE 4 NC (485±30 W) was less than MOPP 4 (515±29 W). Three of five volunteers completed the 100-minute test in both uniforms. The volunteers who did not complete the test in each uniform were removed at the investigator's discretion because the rectal thermistor probes were slipping and could not be adjusted prior to the end of the 100-minute test. Figures 22-28 graphically represent the analyzed data for the SIPE 4 NC vs MOPP 4 tests. T_{re} in SIPE 4 was lower (37.6±0.2°C) than MOPP 4 (37.7±0.1°C). The mean ΔT_{re} was not different between the two uniform configurations at 89 minutes. Regression analyses of the core temperature changes over time indicate a possible stay time of 232 minutes in SIPE 4 NC and 208 minutes in MOPP 4, before soldiers would reach a T_{re} of 39.5°C.

Data were collected at 18.5°C to determine possible problems with heat stress in the cooler temperatures representative of Ft. Benning in December, and secondly, whether there were any differences between the SIPE and MOPP uniform configurations. These data indicate that moderate exercise in fully encapsulated protective posture, in either SIPE or MOPP, would not produce undue heat stress. These findings are in disagreement with the work/rest cycles provided by mathematical modeling (Appendix D, memorandum, SGRD-UE-EMT, 12 Sep 91, Subject: Heat Strain Model with and without Cooling for Climatic Conditions, September - December at Fort Benning, GA) which were purposely very conservative.

SIPE 4 MCC VS MOPP 4, 4-HOUR

Four volunteers attempted the 4-hour SIPE 4 MCC test. One volunteer could not complete the test as he experienced discomfort while breathing through the protective mask. This did not appear to be a problem with the SIPE equipment (which provided positive pressure air-flow to the protective mask in the MCC configuration), but rather a sensitivity of the volunteer to breathing while encapsulated, which plagued him throughout the study. Of the three volunteers who completed the 4-hour experiment,

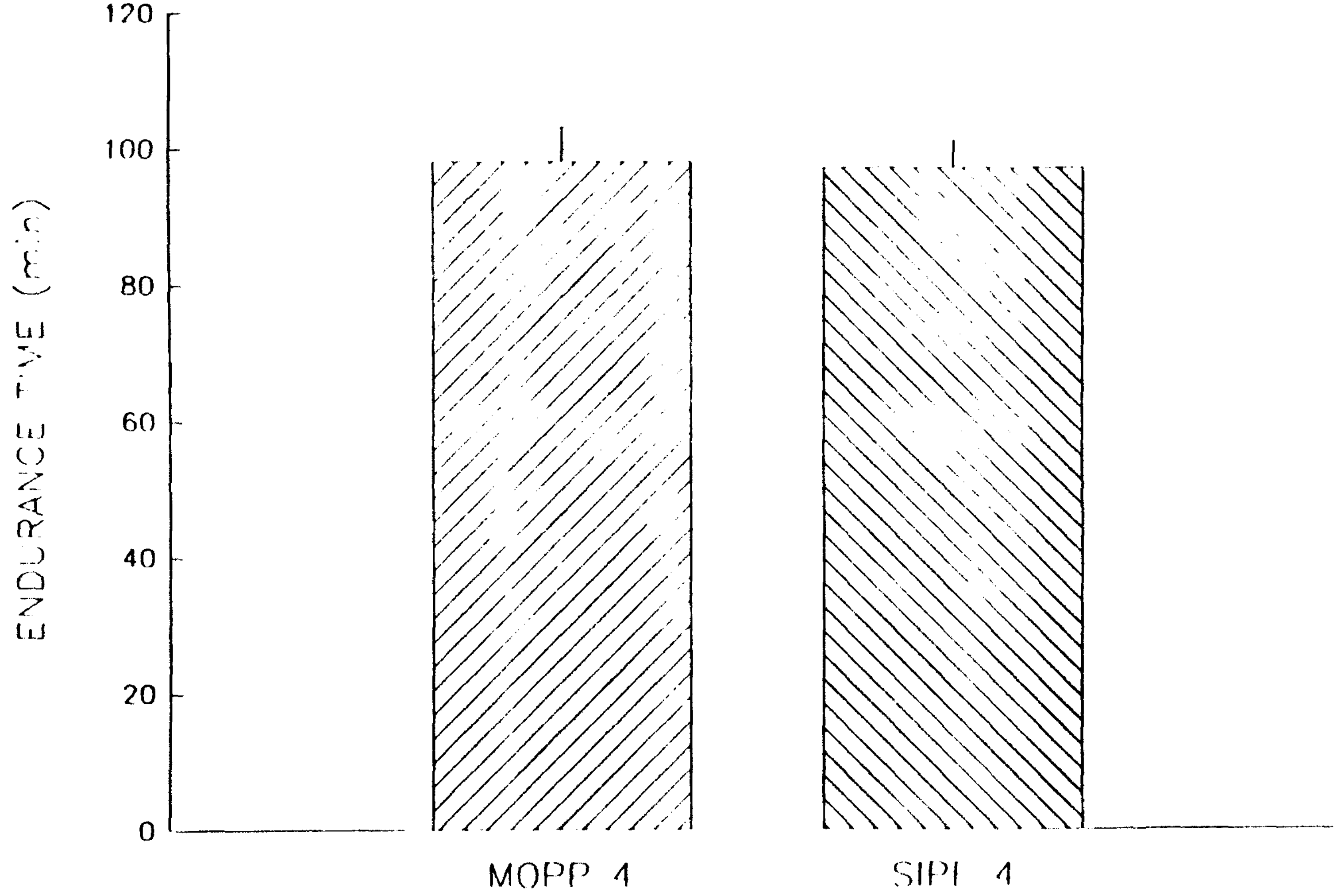

Figure 22. The mean ±SD endurance time of the subjects walking continuously on a treadmill at 1.34 $m \cdot sec^{-1}$, 3% grade in an 18.5°C, 50% rh environment while wearing either MOPP 4 or the SIPI equivalent with no cooling. Maximum experimental time of 100 min.

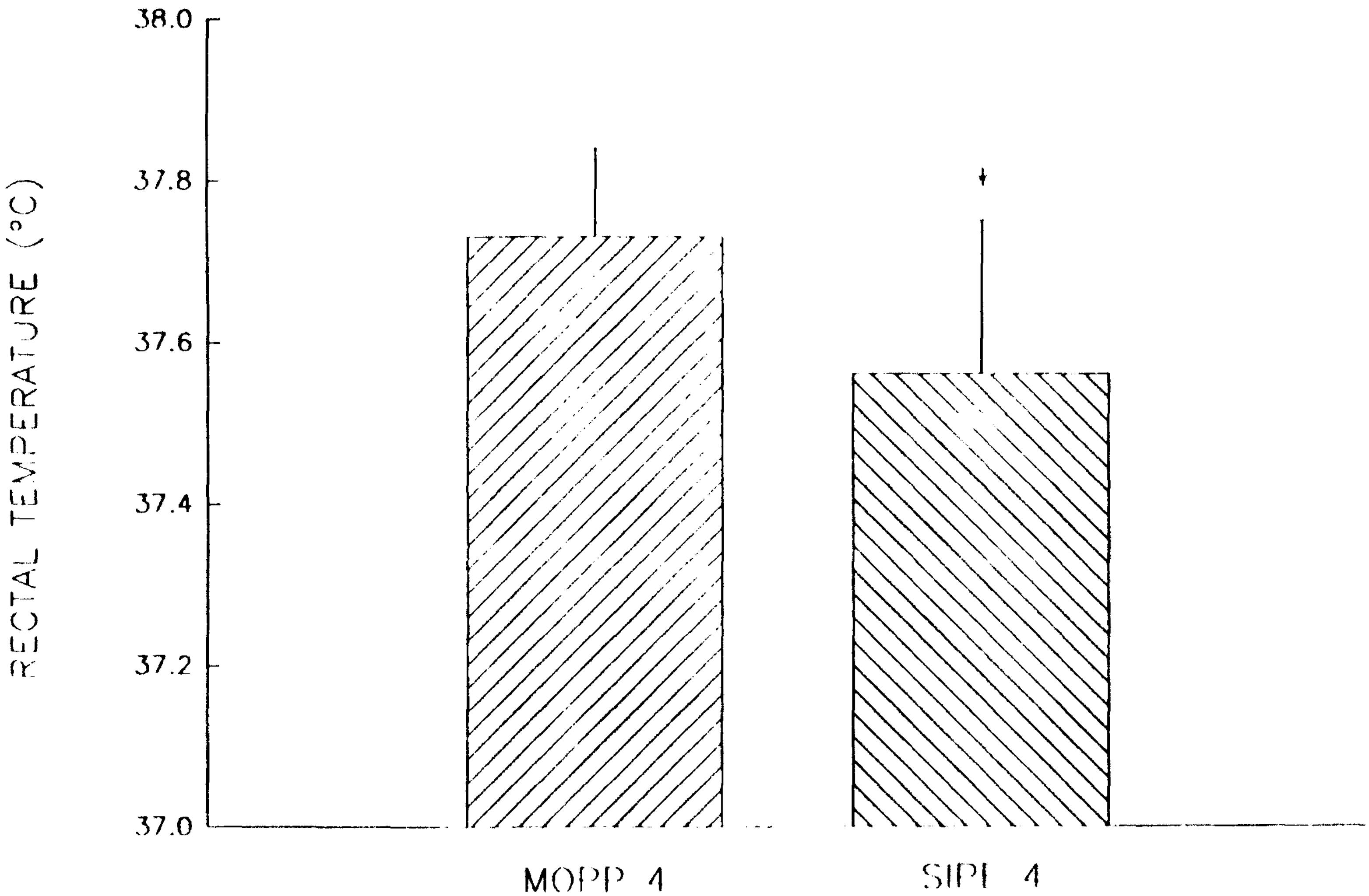

Figure 23. The mean ±SD rectal temperature of the subjects after 89 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in an 18.5°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with no cooling. * Less than MOPP 4.

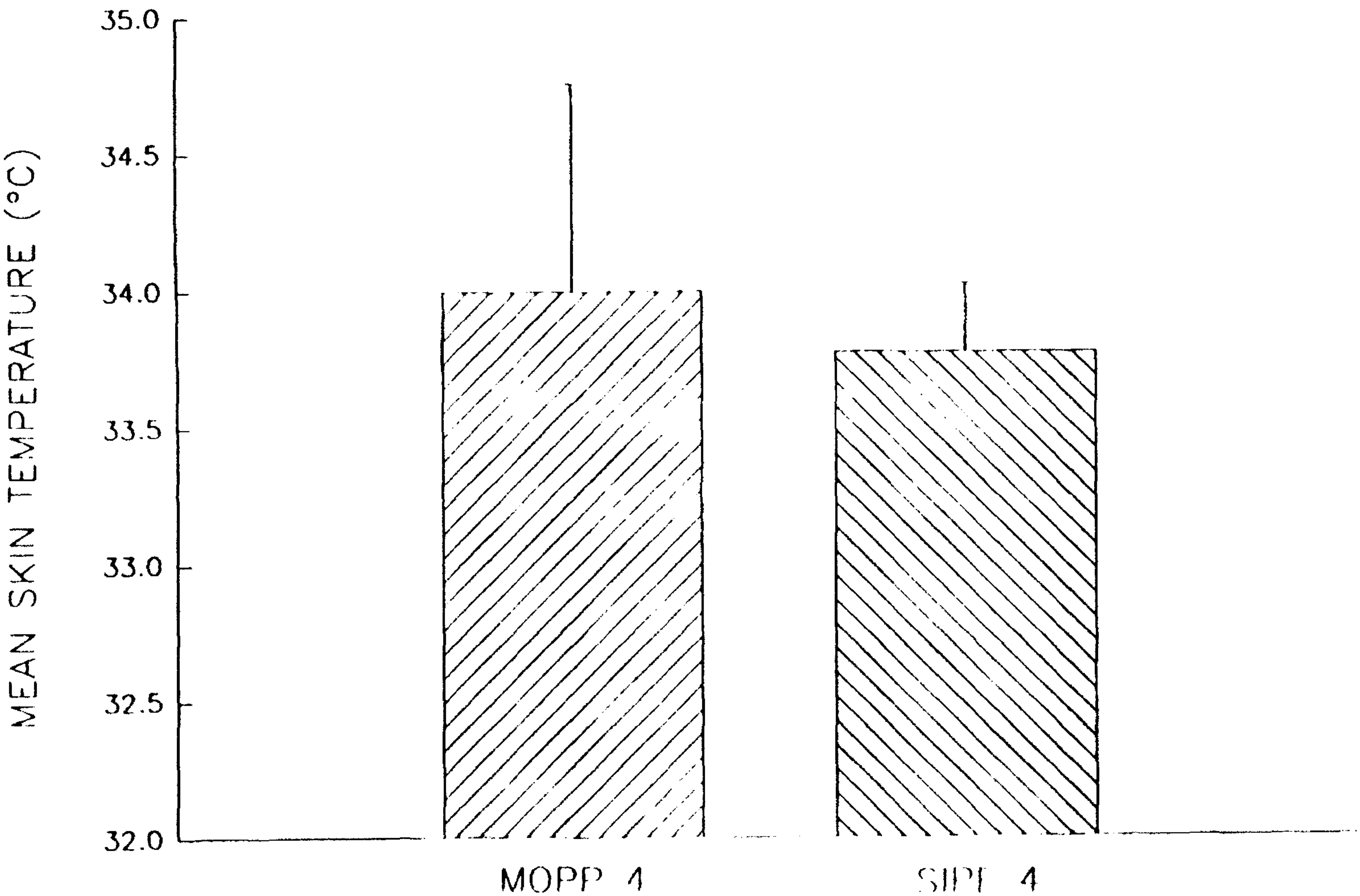

Figure 24. The mean ±SD four point mean skin temperature of the subjects after 89 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in an 18.5°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with no cooling

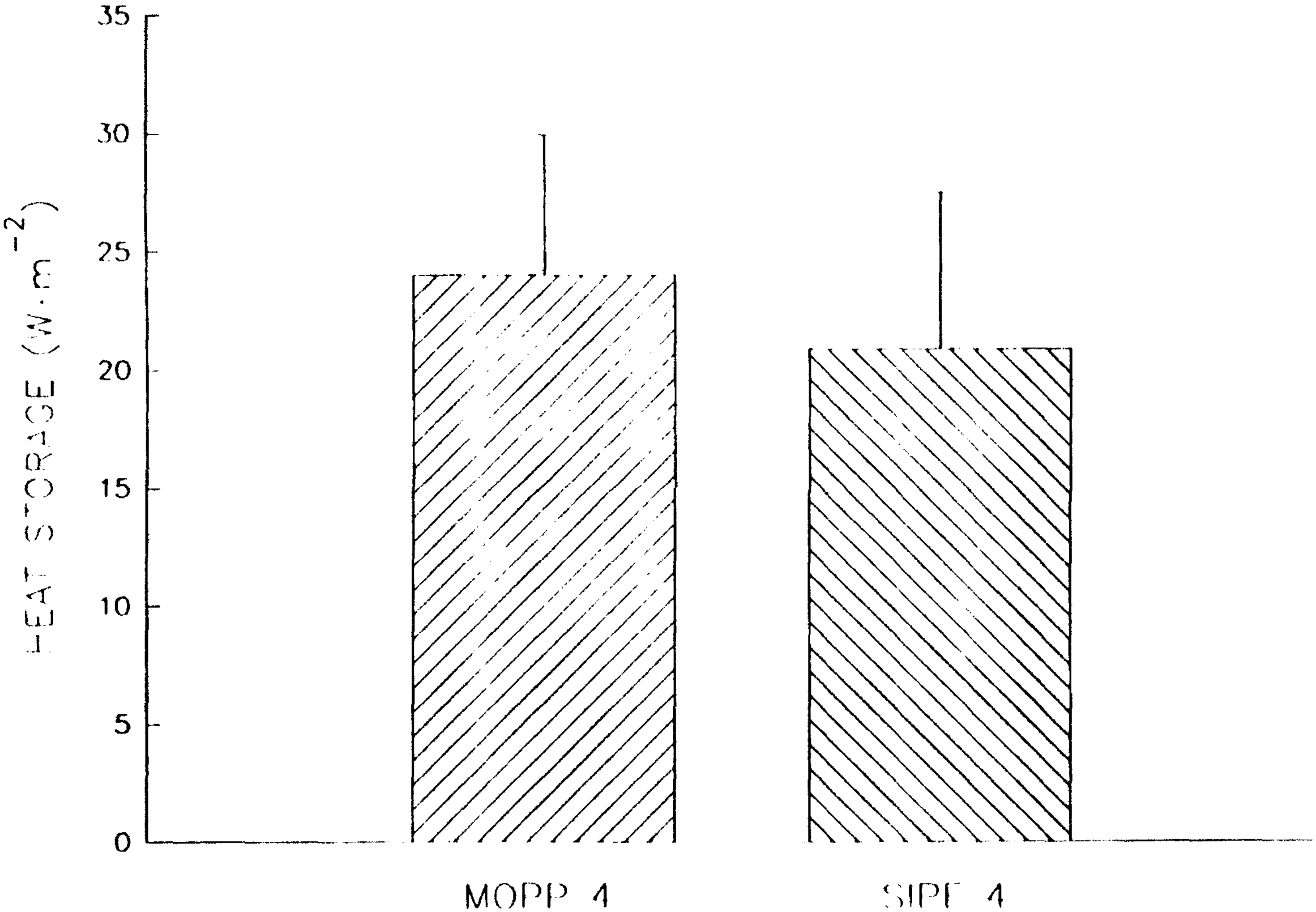

Figure 25. The mean ±SD calculated heat storage of the subjects after up to 100 min of continuous treadmill walking (range 89–100 min) at 1.34 m sec^{-1}, 3% grade in an 18.5°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with no cooling.

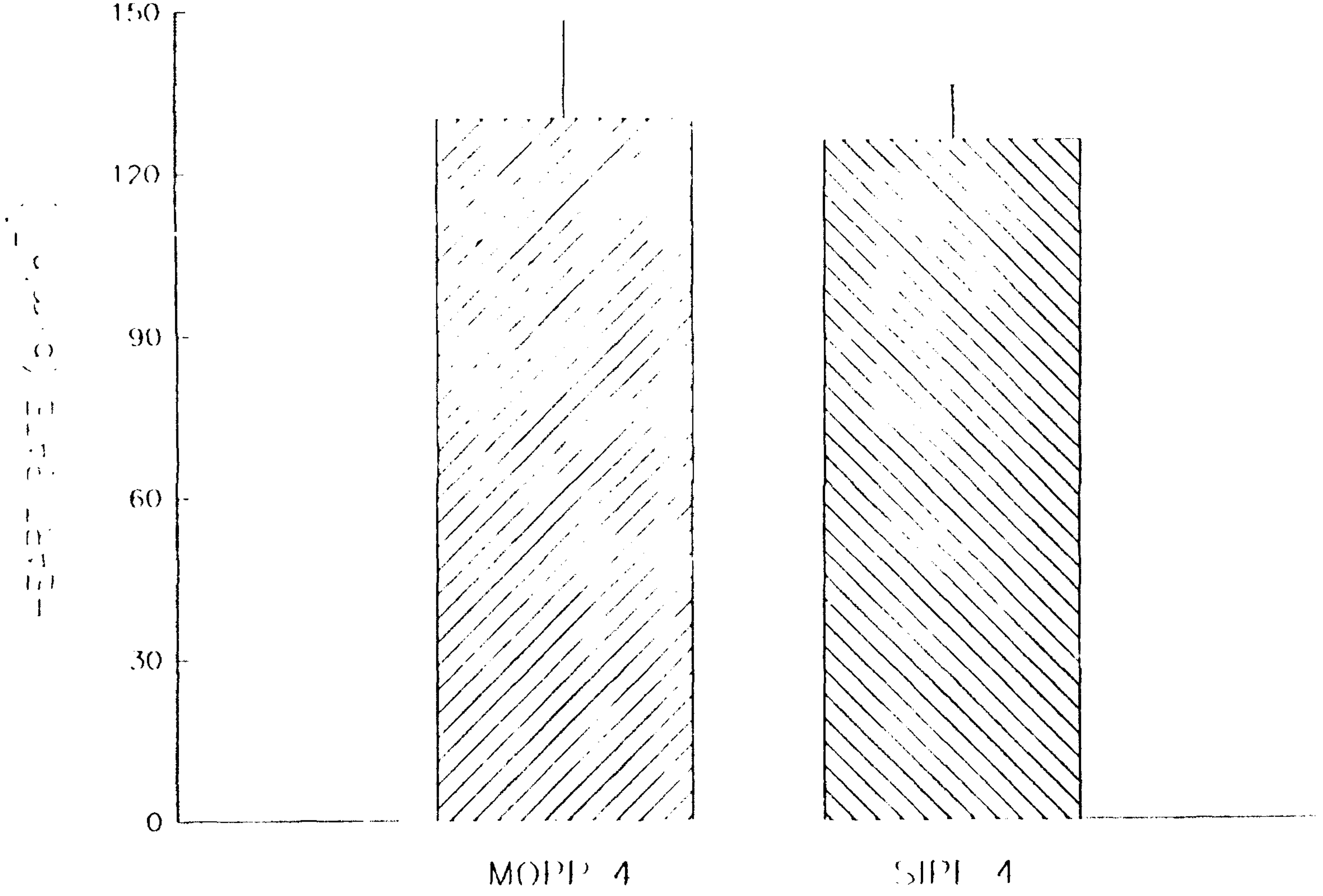

Figure 26. The mean ±SD heart rate of the subjects after 89 min of continuous treadmill walking at 1.34 m·sec^{-1}, 3% grade in an 18.5°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with no cooling.

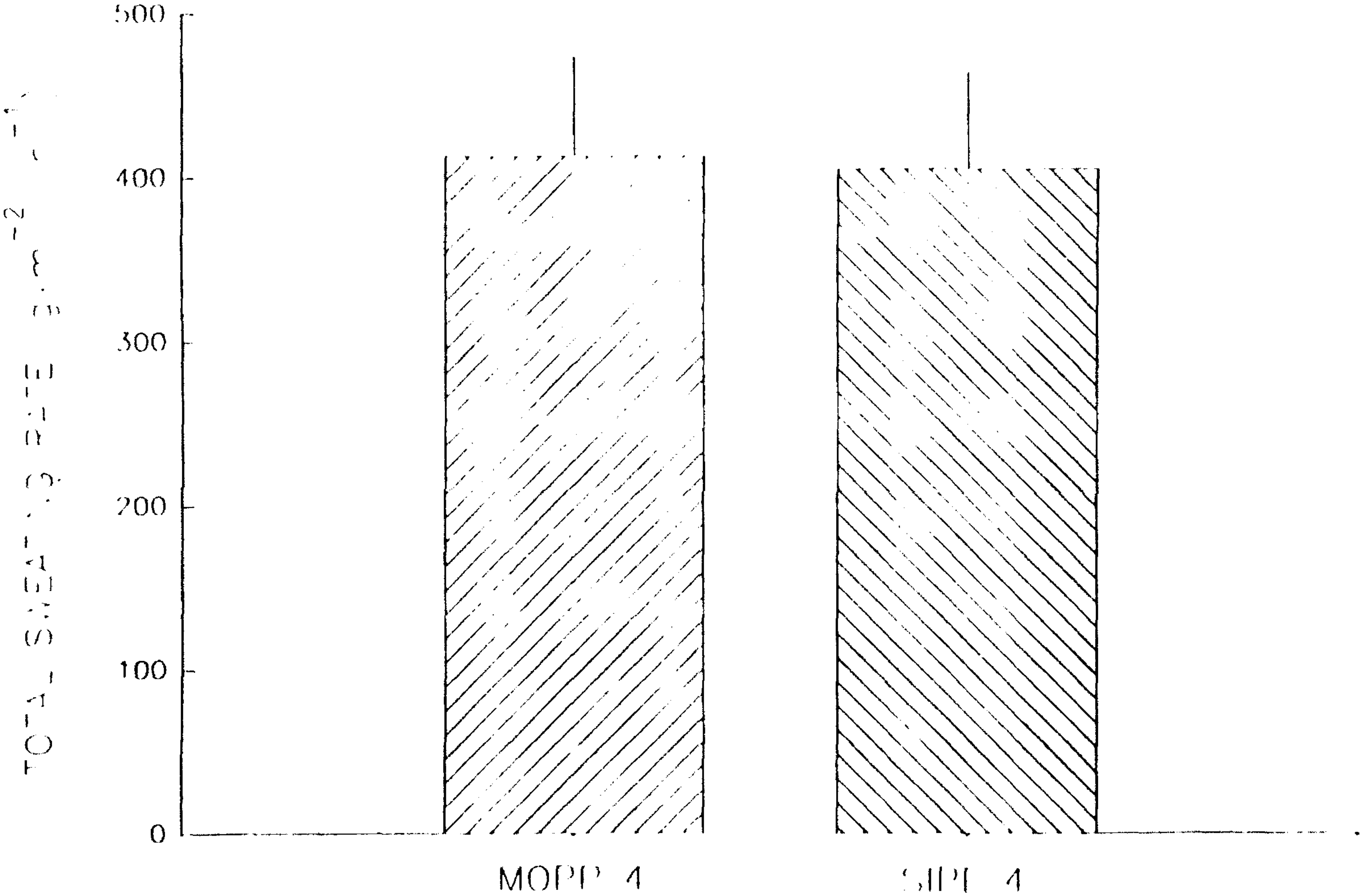

Figure 27. The mean ±SD total sweating rate of the subjects after up to 100 min of continuous treadmill walking (range 89–100 min) at 1.34 m·sec^{-1}, 5% grade in an 18.5°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with no cooling.

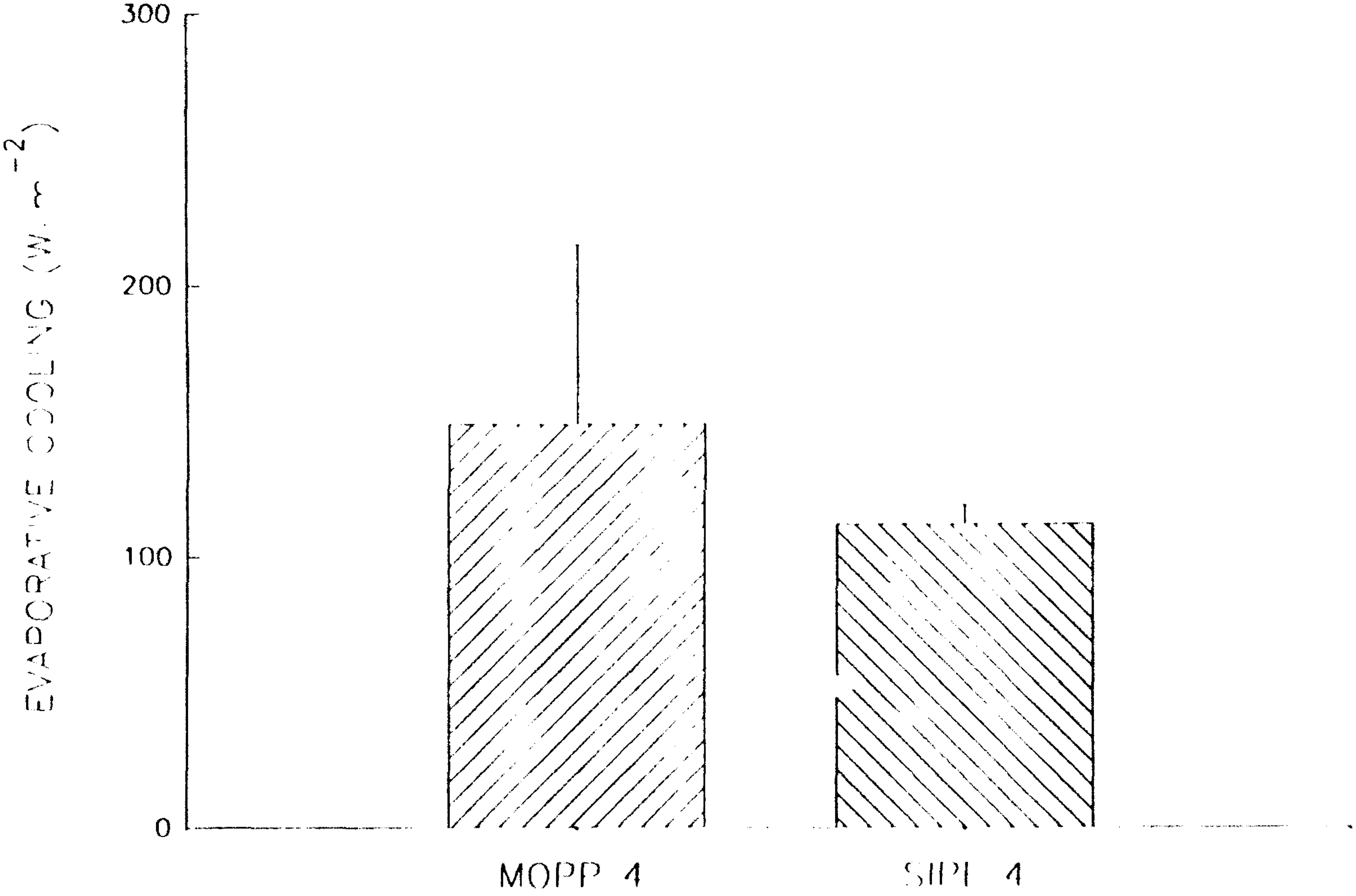

Figure 28. **The mean ±SD evaporative cooling of the subjects after up to 100 min of continuous treadmill walking** (range 89–100 min) at 1.34 m·sec^{-1}, 5% grade in an 18.5°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with no cooling.

none experienced any feelings of inadequate air-flow from the air blown by the MCC to the protective mask.

Minimal thermoregulatory strain occurred during the 4-hour test with SIPE 4 MCC. Figures 29-31 graphically represent the individual T_{re}, chest T_{sk}, and HR at the end of each hour throughout the test. Chest T_{sk} was used rather than $\bar{T}_{sk}$ because so many of the arm, thigh and calf thermocouples broke during the 4-hour tests. For the same reason, it was impossible to calculate S for the 4-hour tests. Figures 32 and 33 show the individual M_{sw}, and E_{tot} for the three volunteers. Only one volunteer completed the 4-hour test in MOPP 4. At the end of the 4-hour test in MOPP 4, this volunteer's final T_{re} was 38.1°C, final chest T_{sk} was 36.9°C, and final HR was 175 b•min^{-1}. At 4 hours in SIPE 4 MCC, his final T_{re} was 37.4°C, final chest T_{sk} was 34.1°C, and final HR was 124 b•min^{-1}. The second volunteer withdrew from the MOPP 4 test at 2 hours and 35 minutes due to chafing in the thighs from the uniform. When this volunteer withdrew from the MOPP 4 test, his T_{re} was 38.1°C, chest T_{sk} was 37.2°C and most recent recorded HR (2 hours and 30 minutes) was 135 b•min^{-1}. At 2 hours and 35 minutes of the SIPE 4 MCC test, his T_{re} was 37.3°C, chest T_{sk} was 35.4°C and most recent recorded HR (2 hours and 30 minutes) was 96 b•min^{-1}. At the end of 4 hours in SIPE 4 MCC, his T_{re} was only 37.5°C (less than the T_{re} at 2 hours and 35 minutes in MOPP 4). The third volunteer withdrew from the MOPP 4 test at 1 hour and 21 minutes due to a blister on his heel. When this volunteer withdrew from the MOPP 4 test, his T_{re} was 37.6°C, chest T_{sk} was 37.0°C and most recent recorded HR (1 hour and 20 minutes) was 128 b•min^{-1}. At 1 hour and 21 minutes of the SIPE 4 MCC test, his T_{re} was 37.5°C, chest T_{sk} was 32.6°C, and most recent recorded HR (1 hour and 20 minutes) was 116 b•min^{-1}. At the end of 4 hours in SIPE 4 MCC, his T_{re} was only 37.7°C (0.1°C higher than the T_{re} at 1 hour and 21 minutes in MOPP 4). These data indicate that the weight of the MCC system is not an overwhelming burden for prolonged use, and that the ambient-air system can be beneficial to job performance at varied workloads.

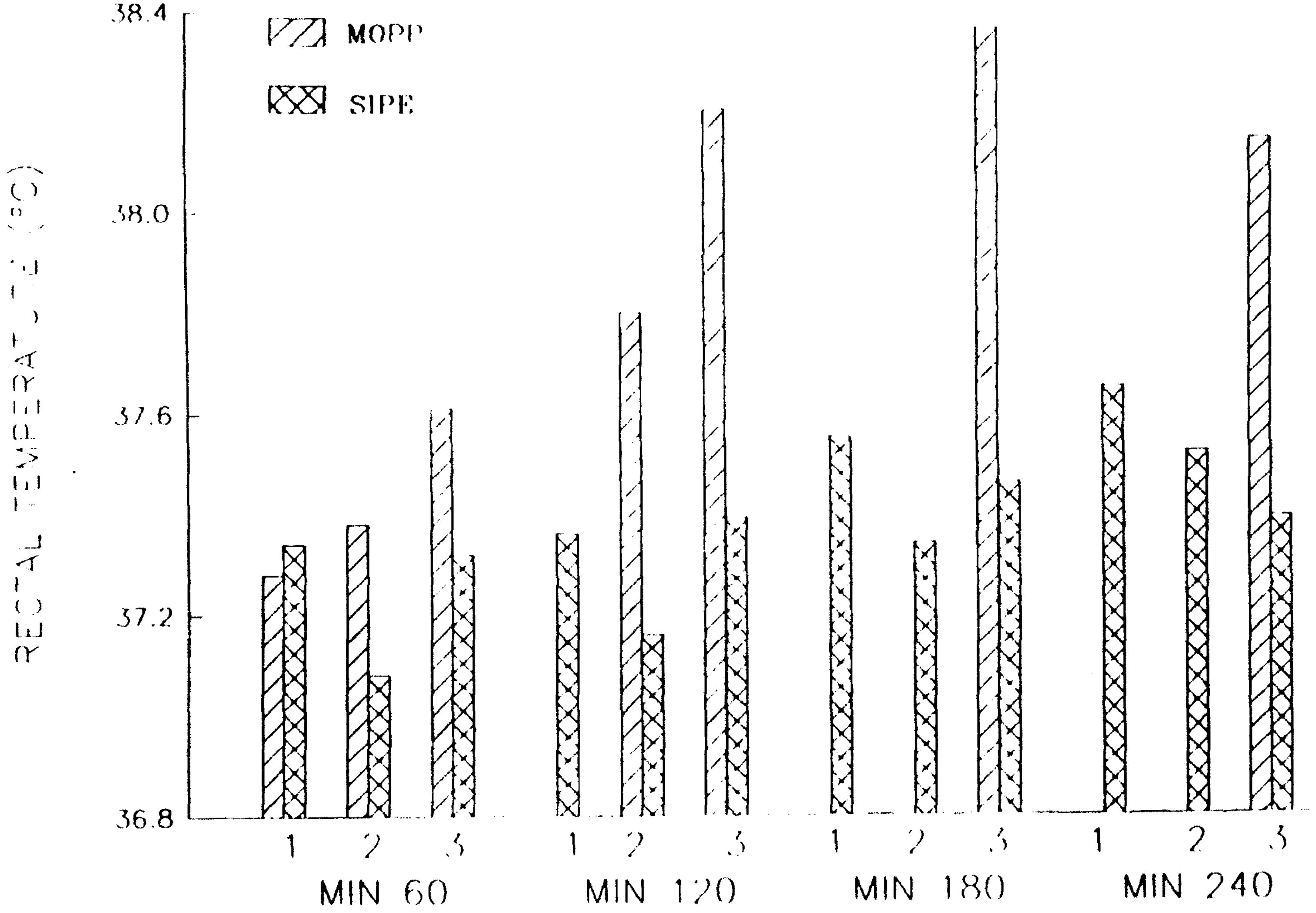

Figure 29. The individual rectal temperatures of the 3 subjects during each hour of the 4 hour experiments in a 30.0°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with ambient air microclimate cooling.

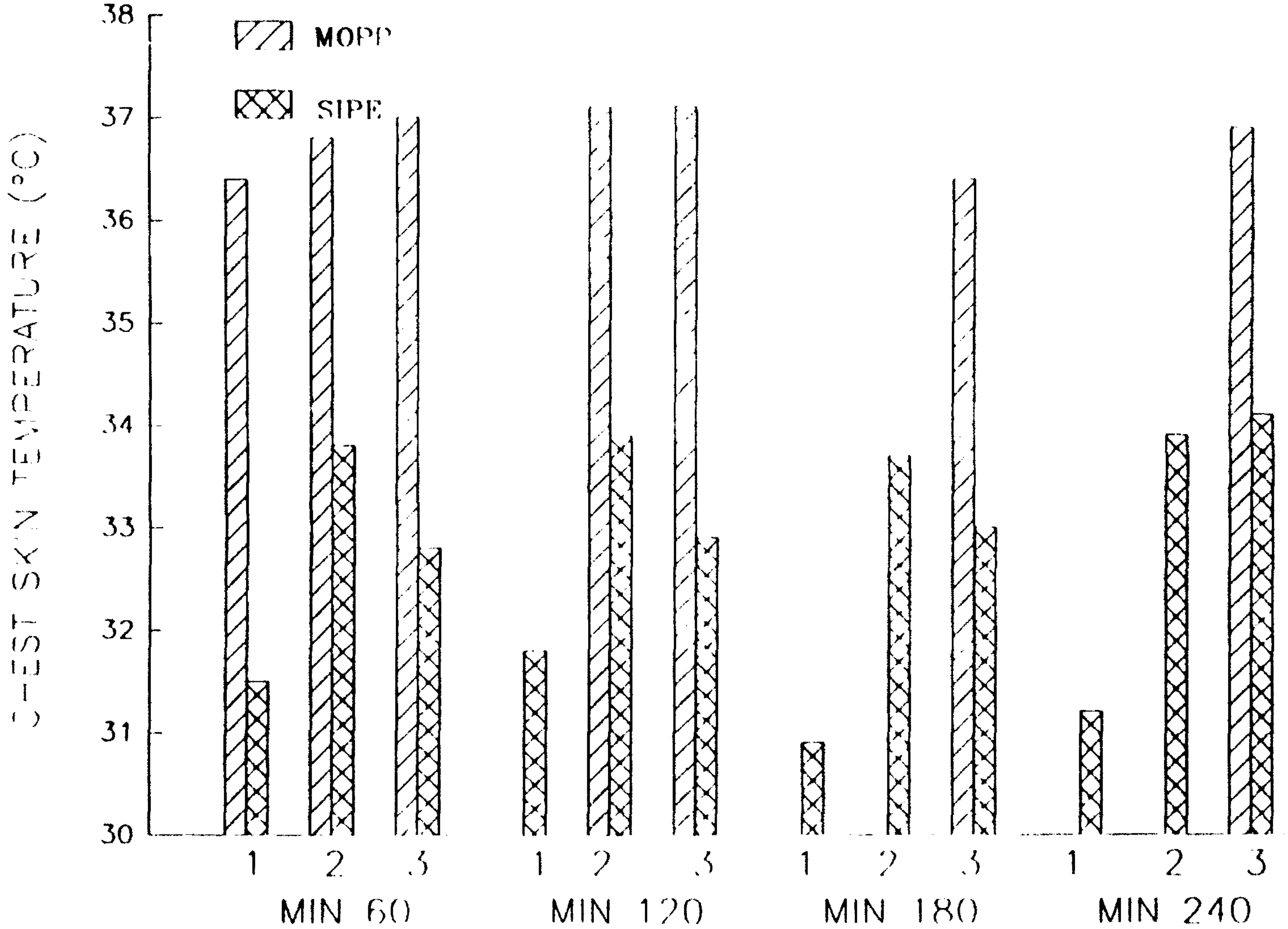

Figure 30. The individual chest skin temperatures of the 3 subjects during each hour of the 4 hour experiments in a 30.0°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with ambient air microclimate cooling.

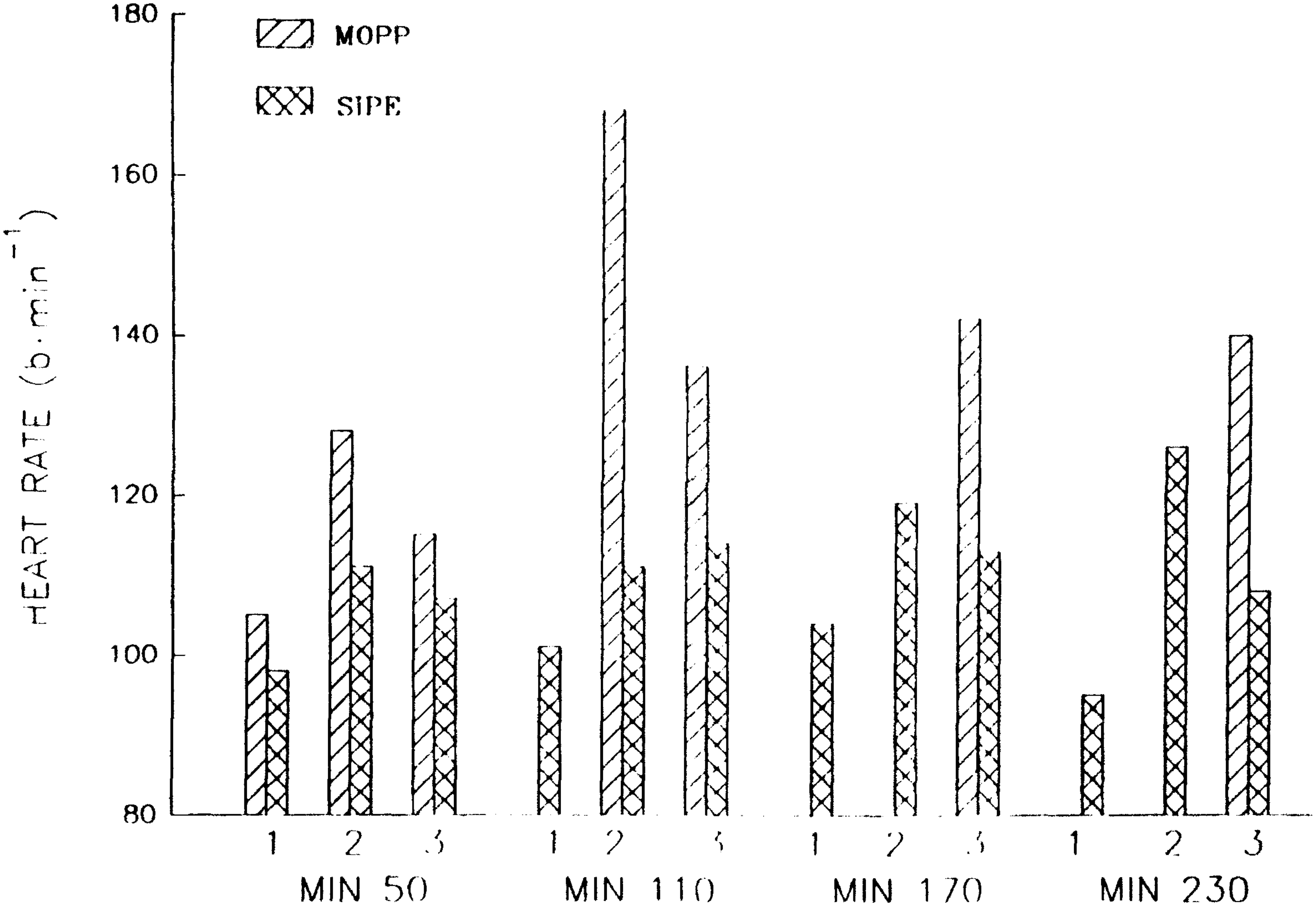

Figure 31. The individual heart rates of the 3 subjects during each hour of the 4-hour experiments in a 30.0°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with ambient air microclimate cooling.

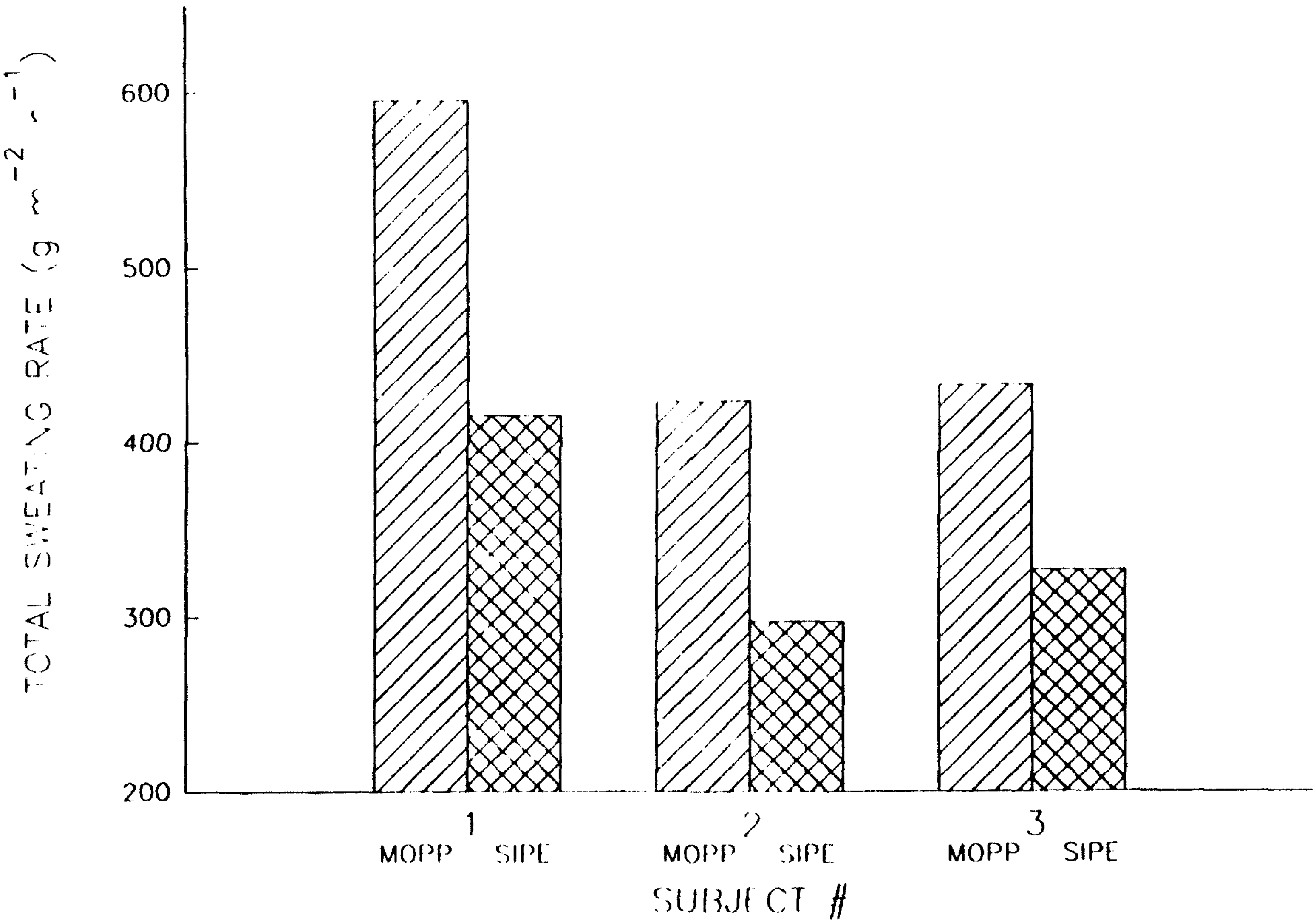

Figure 32. The individual total sweating rate of each subject during the 4-hour experiments in a 30.0°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with ambient air microclimate cooling.

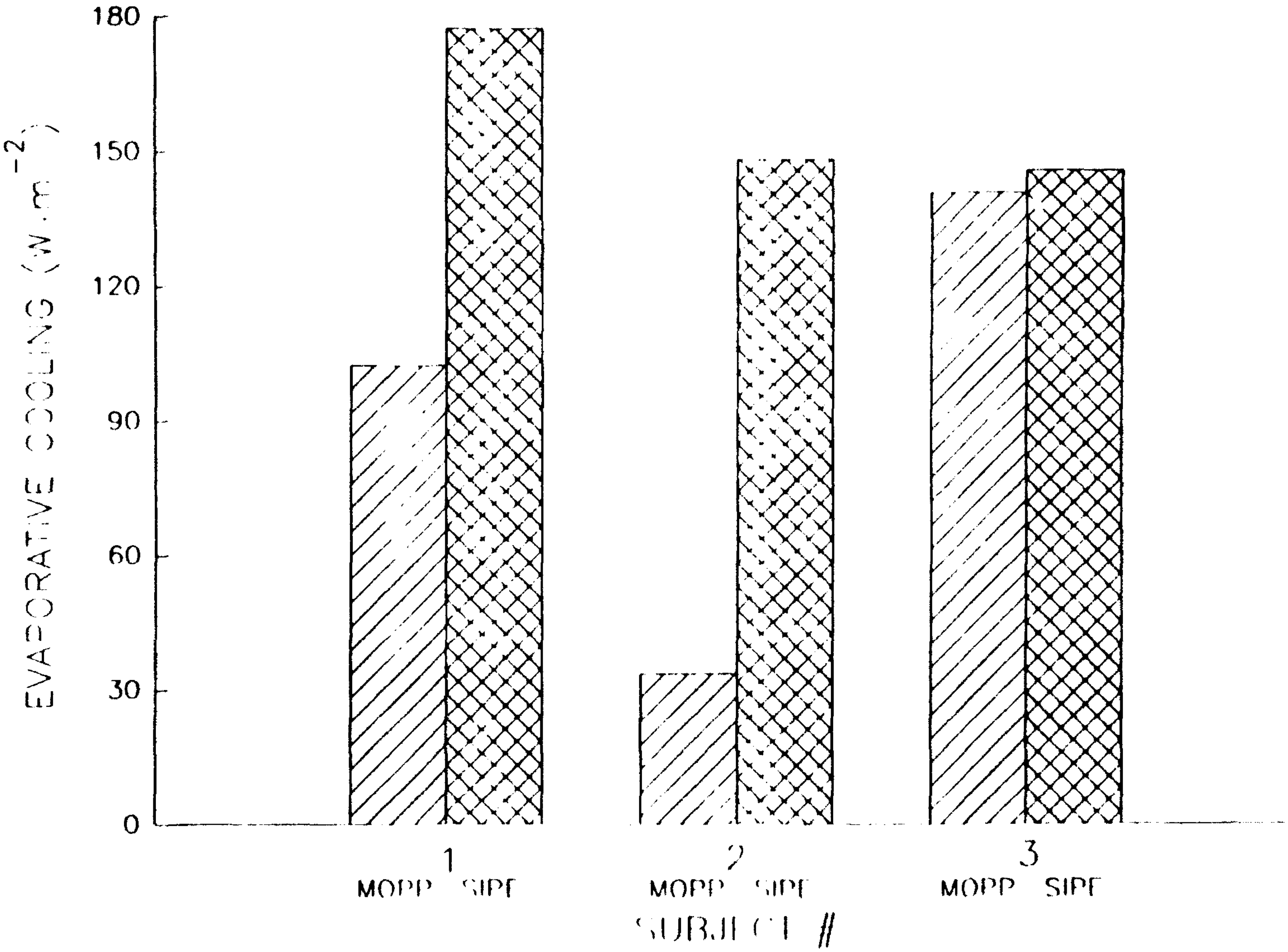

Figure 33. The individual evaporative cooling rate of each subject during the 4-hour experiments in a 30.0°C, 50% rh environment while wearing either MOPP 4 or the SIPE equivalent with ambient air microclimate cooling

CONCLUSIONS

In general, physiological responses to the SIPE uniform configurations were nearly identical to the equivalent standard MOPP configurations in both the 30.0°C and 18.5°C environments. This would indicate there should be no decrement in soldier performance due to the SIPE clothing system when operating in a temperate environment. Because the SIPE uniform is developmental, it is important to understand that changes in either the fabric used in the ACU or the amount of water repellant treatment used on the ACU could change the insulation or permeability of the material and affect the physiological responses of the soldiers wearing the uniform.

Although the MCC increased the weight carriage of the soldiers by approximately 10 kg, it significantly improved thermoregulation in the temperate environment tested. If the ambient air temperature was higher than 35°C, no temperature gradient would exist between skin and the air blown over it by the MCC vest to aid in convective cooling. However, there could still be some benefit from evaporation if there was a difference between the water vapor pressure above the skin surface and the air provided by the MCC vest.

As currently designed for the SIPE system, the relationship between the C2 canister, the hose connecting it to the protective mask, and the mask itself increases inspiratory resistance relative to the design of the mask for standard use where the C2 canister is screwed directly into the mask. This design can result in decreased performance of the soldiers wearing the SIPE clothing system in an NBC configuration compared to soldiers in the standard MOPP configuration. If the hose between the C2 canister and the protective mask were shortened and redesigned to reduce the resistance, endurance time in the SIPE 4 NC configuration should increase to be similar to MOPP 4 endurance times.

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APPENDIX A

SIPE DETAILED SYSTEM DESCRIPTION

SIPE INTEGRATED HEADGEAR

The Integrated Headgear Subsystem (IHS) is a modularly designed integrated protective system. The system consists of two primary components (IHS Ballistic Shell and Power Supply), and four modular subcomponents (Ballistic/Electro-Optic Visor, Communication, Suspension Liner, and Respiratory Protective Device). Based on specialized mission requirements, the five subcomponents are interchangeable within the IHS Ballistic Shell. The subcomponents work independently of each other (housed within the ballistic shell), and are also capable of operating with any combination of subcomponents and all subcomponents together as required or mandated by the mission requirements and/or soldiers' responsibilities. The IHS subsystem affords the user the following performance/protection criteria: complete ballistic protection for the head and eyes, soldier-to-soldier short- and long-range communications along with state-of-the art aural protection, countersurveillance, state-of-the-art protection against nuclear, biological and chemical (NBC) threats of the modern battlefield, laser eye protection, and a helmet mounted display that serves as a remote viewing device for the weapon's fire control system, day and night vision enhancement, and Soldier's Computer viewing platform. The IHS Ballistic Shell and modular (flip up/down) visor serves as a mounting base for all subcomponents.

a. Ballistic Shell Component (BSC)

The BSC is an Open Face Helmet (OFH) ballistic shell that is constructed of a fiber-based composite. The shell has a similar configuration to the PASGT helmet and weighs approximately three pounds (1300 g). The shell is the mounting base for the four IHS subcomponents. The subcomponents are: the Ballistic Visor Subcomponent (BVS), the Communications Subcomponent (COMS), the Suspension Liner Subcomponent (SLS), and the Respiratory Protective Device (RPD).

1. Ballistic Visor Subcomponent: The BVS is a flip up/down modular ballistic subcomponent that will house the following components or subcomponents. They

include: the Ballistic Transparency (BT), a 2.5 mm thick thermal formed sheet of polycarbonate;Laser Eye Protection, a passive, dye absorber thin film insert fixed to the inside surface of the BT; and the Electro-Optics (EOS) Vision Enhancement Receiver Group and Display Optics. The EOS includes a GEN III Image Intensifier Tube, Hughes Cathode Ray Tube (CRT) and glass lenses for the helmet mounted display (display optics). The driver electronics and power supply are carried in a backpack on the load-bearing component.

2. Communications Subcomponent (COMS): The COMS is an integral part of the BSC and SLS. Integrated into these components is a bone conduction microphone mounted within the brow pad of the SLS, two electronic earplugs (one for each ear), used for aural protection and communications, a pre-amp, ambient sound listening microphone with wiring, and a connector for the COMS module (carried in backpack) interface.

3. Respiratory Protective Device (RPD): The RPD is a modified XM-44 protective mask that includes reduced profile lenses and modified suspension, Hydration Liquid Nutrient (HLN) transport line (hose from canteen), hand pump, connectors for mask and canteen, a mouthpiece inside mask, and a powered voicemitter for face-to-face communications. A double-shirted butyl rubber hood interfaces with the XM-44 Mask and Advanced Clothing Subsystem.

4. Suspension Liner Subcomponent (SLS): The SLS includes a modified cradle suspension with a rigid, foam padded headband. Attached to the headband is an adjustable ratchet nape strap for increased stability along with a drawstring crown adjustment and pad. The SLS also uses the standard two-point chin strap with a webbing chin cup and adjustment buckles on both sides.

b. Power Supply Component (PSC)

The PSC consists of two subcomponents: (a) the Main Power Supply Interface and (b) the Backup Power Supply.

1. Main Power Interface is a quick connect/disconnect interface that will relay the power from an external power supply (batteries) from the Microclimate

Conditioning/Power Subsystem (MCC/PS) to the headgear, EOS and COMS components.

2. The Backup Power Supply is a battery pack that will be housed within the EOS backpack and carried on the Load Bearing Component of the ACS.

SIPE ADVANCED CLOTHING SUBSYSTEM

The function of the Advanced Clothing Subsystem (ACS) is to improve the lethality of the soldier by providing balanced multiple threat protection in a modular, integrated head-to-toe clothing system. The system will allow for greater mobility and operational effectiveness through its inherent design features, capability for mission tailoring and sizing/fit based upon the current U.S. Army anthropometrics.

The ACS consists of eight subcomponents (listed as worn outer to inner in full-up configuration):

Load Bearing Component
Ballistic Protective Vest
Advanced Shell Garment (Jacket and Trouser)
Advanced Combat Uniform (Jacket and Trouser)
Chemical Vapor Undergarment
Active Cooling Vest
Waste Management System (PAD)
Handwear
Footwear

The Load Bearing Component (LBC) houses the MCC/PS, facilitates secondary ammunition carrying capability and provides cargo (and miscellaneous equipment) carrying capability. The system is designed to compatibly interface with the Ballistic Protective Vest and the Integrated Headgear System (IHS). The LBC allows for individual sizing, provides protection against visual detection and features a jettison capability, enabling the load to be streamlined when necessary.

The Ballistic Protective Vest (BPV) will provide fragmentation and flechette protection to the upper torso through state-of-the-art materials and configuration. The side closing vest facilitates primary ammunition carrying capability, attachment of the Helmet Control Unit (HCU), provides environmental and visual detection protection, and is compatible with all other ACS subcomponents. The BPV is sized, fitted and designed to be worn over the Advanced Combat Uniform, and either over or under the Advanced Shell Garment Jacket/Trouser.

The Advanced Shell Garment (ASG, Jacket/Trouser) provides protection against environmental, flame and energy threats. By including a semi-permeable membrane in the shell fabric, the ASG also provides protection against liquid and aerosol chemical threats. The ASG is worn over the Advanced Combat Uniform. Placement relative to the LBC and BPV is scenario dependent, yet garment design/sizing allows for the ASG to be worn over or under these subcomponents. The clothing design allows for compatibility with all ACS subcomponents including a reliable (i.e. chemical protective) interface with the handwear and footwear subcomponents as well as the IHS.

The Advanced Combat Uniform (ACU) is the baseline uniform which provides protection against environmental, flame and energy threats. The design and objective closely follow the current Battle Dress Uniform (BDU). The ACU is sized/fitted to accommodate the Chemical Vapor Undergarment, the Active Cooling Vest and the Waste Management System.

The Chemical Vapor Undergarment is a two-piece garment which provides protection against a chemical vapor threat through an activated carbon fabric. The undergarment is designed to provide a streamlined, comfortable fit as well as provide maximum area of coverage.

The Active Cooling Vest is based upon the Army's Generation II Microclimatic Cooling Vest. The ACV distributes 15 cfm (~150 watts) of filtered air across the torso. The improved spacer fabric is incorporated in a T-shirt design which, through fabric technology, provides a degree of passive cooling. The spacer fabric may be removed for laundering of the T-shirt. The ACS clothing layers are designed with the appropriate pass-throughs to facilitate the ACV manifold.

The Waste Management System (for collection of liquid waste) will be based upon a unisex personal adsorptive device (PAD) which is stored within a waste management brief. Constructed of a combination gel and highly adsorptive material, the PAD resembles a sanitary napkin in size and shape. The PAD will remain in the brief chamber during the mission and, if soiled, removed at the completion of the mission.

The ACS handwear component will be a two-glove system: a stand alone combat glove and chemical protective glove. The combat glove will be of a knit construction, providing protection from flame, visual detection and energy threats. The palmar surface and fingertips of the glove will be coated/treated to enhance grip. The chemical protective glove will be a three-layer material system which will provide liquid, vapor and aerosol chemical protection as well as flame protection and POL resistance. The inner layer will provide vapor protection through an activated carbon knit fabric, while the intermediate layer will provide liquid/aerosol protection via a semi-permeable membrane. The outer shell will be a simplex knit, which utilizes the fourchette design for enhanced dexterity and fit. The glove system will provide for a reliable interface with the ASG jacket cuff. All gloves will be brown.

The ACS footwear component will consist of a lightweight combat boot and a chemical protective gaiter. The lightweight boot utilizes state-of-the-art materials and fabrication technologies (e.g., direct molded sole) to improve protection (environmental and flame/energy), fit and comfort. The gaiter is designed to fit over the lightweight combat boot, using a rubber band to attach the gaiter to the sole of the boot. The gaiter upper is constructed of a combination of materials layered to provide chemical protection, protection from energy threats, visual detection and flame. An elastic drawcord located at the gaiter upper edge will facilitate a positive interface with the ASG trouser. The ASG trouser is worn over the gaiter to prohibit chemical run-off into the boot. The SIPE boot will be brown.

MICROCLIMATE CONDITIONING/POWER SUBSYSTEM

The Microclimate Conditioning/Power Subsystem (MCC/PS) has two primary functions: to reduce heat stress and provide positive pressure breathing to the soldier.

The MCC/PS will reduce heat stress by providing ambient air inside the ACS and IHS for the SIPE soldier. Ambient air was chosen from several MCC technologies as a low risk approach. This type of MCC has been proven to be very effective in a temperate environment. Ambient air's primary mechanism for heat removal is evaporation. The perspiration on the skin is evaporated by the flow of ambient air over it.

The MCC/PS consists of three main components: the blower, the filter and the power source. The blower component was designed to provide 18 cfm of air at 8" water column of back pressure. It is powered by a 24-VDC source and weighs 4.0 pounds. The noise output is 70 dBa or less at one meter when operating with no back pressure.

The ambient air will pass through the filter before it is drawn into the blower. This component will filter 18 cfm for contaminants. The pressure drop through the filter will be approximately 4.0" water column or less. The filter case will be constructed of lightweight materials to minimize the weight. It should weigh less than 5.0 pounds. The openings in the filter must be protected so as not to allow interference by the environmental elements. Filter design was performed by the U.S. Army Chemical Research, Development and Engineering Center (CRDEC) in Aberdeen Proving Ground, Maryland.

The power component of the MCC/PS must supply 70 watts at 24-VDC for the MCC blower component. It must be able to supply power for six continuous hours without re-supply and have a high power density. For the SIPE program, the best power source available is a lithium-based battery. The recently introduced BA-6590 U provides 12.8 amp-hours at 24-VDC, has a 2.2 amp slow blow fuse, and weighs 2.75 pounds. Two of these batteries in parallel will power the SIPE/MCC/PS.

Several secure and reliable mechanisms to provide a durable interface with the ACS and IHS are required as outlined below.

a. The blower will couple with the active cooling vest of the ACS as the air distribution mechanism.

b. The blower will also provide air into an opening of the modified XM-44 mask being used with the IHS. This will provide breathing air to the oronasal cavity. In order to provide air to both the IHS and the ACS, a mechanism will be employed to split the air stream exiting the blower. A small portion of the stream (3 cfm) will be directed to the IHS, while the remaining 15 cfm will go to the ACS. This mechanism used will be the standard Army Y-connector.

c. The MCC/PS will be mounted to the LBC, an ACS component. It will be considered a noncombat essential portion of the load. The subsystem is able to quick-disconnect (jettison) from the LBC. Hosing and wiring will be considered in the quick-disconnect design, as well as the three components of the subsystem.

APPENDIX B

MOPP AND SIPE COMPONENTS WORN DURING TESTING

MOPP 0

WEAR:
- T-SHIRT
- LYCRA® SHORTS
- SOCKS
- BATTLE DRESS UNIFORM (BDU)
- COMBAT BOOTS
- BODY ARMOR
- HELMET

MOPP 1

WEAR:
- T-SHIRT
- LYCRA® SHORTS
- SOCKS
- BATTLE DRESS OVERGARMENT (BDO)
- COMBAT BOOTS
- BODY ARMOR
- HELMET

CARRY:
- C/B PROTECTIVE MASK
- BUTYL HOOD
- BUTYL GLOVES
- GLOVE LINERS
- OVERSHOES

MOPP 4

WEAR:
- T-SHIRT
- LYCRA® SHORTS
- SOCKS
- BDO
- COMBAT BOOTS
- BODY ARMOR
- HELMET
- C/B PROTECTIVE MASK
- BUTYL HOOD
- BUTYL GLOVES
- GLOVE LINERS
- OVERSHOES

SIPE 0

WEAR:

- COOLMAX® T-SHIRT
- LYCRA® SHORTS
- SOCKS
- ADVANCED COMBAT UNIFORM (ACU)
- COMBAT BOOTS
- BODY ARMOR
- HELMET

SIPE 1

WEAR:

- COOLMAX® T-SHIRT
- LYCRA® SHORTS
- SOCKS
- CHEMICAL VAPOR UNDERGARMENT (CVU)
- ACU
- HELMET
- TORSO ARMOR
- BOOTS

CARRY:

- CHEMICAL GLOVES
- C/B PROTECTIVE MASK

SIPE 4

WEAR:

- COOLMAX® T-SHIRT
- LYCRA® SHORTS
- SOCKS
- CVU
- ASG
- HELMET
- TORSO ARMOR
- BOOTS
- CHEMICAL GLOVES
- C/B PROTECTIVE MASK

*MICROCLIMATE CONDITIONING
*POWER SYSTEM

* PROVIDES COOLING IN TWO SIPE 4 EXPERIMENTS

APPENDIX C

SCHEDULE FOR 4-HOUR TESTS

TIME (MIN)	ACTIVITY
0-5	SEATED REST
5-20	WALK 3 MPH, 3% GRADE
20-30	SEATED REST
30-50	WALK 2 MPH, 0% GRADE
50-55	WALK 3.5 MPH, 3% GRADE
55-60	SEATED REST

REPEAT SCHEDULE 4 TIMES

APPENDIX D

DEPARTMENT OF THE ARMY
US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
NATICK, MASSACHUSETTS 01760-5007

SGRD-UE-EMT (70) 12 September 1991

MEMORANDUM THRU Director, Environmental Physiology and Medicine Directorate, U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760-
MA 01760-5007

FOR Commander, U.S. Army Natick, Research, Development and Engineering Center, ATTN: STRNC-TTE (Ms. C. Fitzgerald, Army SIPE Manager), Natick, MA 01760

SUBJECT: Heat Strain Model with and without Cooling for Climatic Conditions September - December at Fort Benning, GA

1. The USARIEM Heat Strain Model was used to predict work performance of heat acclimated, fully hydrated soldiers wearing NBC clothing (theoretical values CLO = 2.4, i_m = 0.30) with no cooling available. The predictions were made during four military work levels (very light, 150 watts; light, 250 watts; moderate, 425 watts; heavy, 600 watts) in the environmental conditions typical of average daily high temperatures at Ft. Benning, GA, from September through December (Table 1). These metabolic values are the standard default work levels of the heat strain model. Soldiers carrying 20-30 kg of weight (as noted in the tasking letter) would probably be within the 450 to 600 watt range for metabolic rates during most military tasks.

2. Tables 2A, 2B, and 2C provide predicted work/rest cycles and maximal work times during the average daily high temperature of each month. The predictions are made for a low casualty rate (2A, less than 5% heat casualties), a moderate casualty rate (2B, 20% heat casualties) and a high casualty rate (2C, 50% heat casualties). For very light (sedentary) activity, no limits exist for work time. However, most infantry soldier tasks will correspond to moderate intensity work. For moderate and heavy intensity work, sustainable work/rest ratios with low casualties could not be employed until November and December.

3. A model under development by the Biophysics and Biomedical Modeling Division was used to predict the effects of ambient air microclimate cooling on heat storage (Table 3 and 4). The calculations were based on using the average daily high temperature for each month and receiving ambient air to the torso at flow rates of either 15 scfm (Table 3) or 5 scfm (Table 4). Using the high flow rate (Table 3), microclimate cooling should reduce the rate of heat storage under all conditions except high

intensity work in September, when the metabolic rate is greater than the cooling potential from the ambient air. In fact, the model predicts that at the high flow rate the soldiers will receive excessive localized cooling with possible asymetric cold discomfort during October, November and December. Assuming that the SIPE soldier will be able to adjust the microclimate cooling flow rate, we also calculated values for a low flow rate. At 5 scfm, microclimate cooling should still be sufficient to reduce the rate of heat storage under all conditions except during moderate and heavy work in September and heavy work in October. Even at the low flow rate the air vest model predicts localized asymetric cold discomfort coupled with limited total body cooling at moderate work in November and at both moderate and heavy work in December.

4. The results indicate that while the high ambient temperatures possible in September and October would limit the daily work time for soldiers in NBC clothing without cooling, ambient air microclimate cooling should increase performance times except at the highest temperatures and most severe work loads. During cooler periods and at lower metabolic levels, the predictions indicate ambient air could provide excessive cooling and soldiers will need to adjust the flow control to remain comfortable.

5. Examination of the technical summary "1990 Light Data and Climatology for Ft Benning GA", supplied by the 5th Weather Squadron of Ft. Benning shows September to be the third driest month of the year averaging 8 days with rain and a total rainfall of 3.5 inches. September also averages 11 days with temperatures above 32°C. October is the driest month of the year averaging 5 days of rain and a total rainfall of 1.8 inches. October also averages 0 days with temperatures above 32°C and one day with temperatures below 2°C. November is the second driest month averaging 7 days of rain and a total rainfall of 3.1 inches. November also averages 0 days with temperatures above 32°C and 5 days with temperatures below freezing. December is the third wettest month averaging 10 days of rain and a total rainfall of 4.9 inches. December also averages 12 days with temperatures below freezing, and an average of 7-8 cold fronts moving through the area.

6. In summary, moderate work while encapsulated in NBC clothing with no cooling will be limited to short time periods with prolonged breaks necessary throughout September - December. Periods of high ambient temperature will also limit work times, even with ambient cooling provided. October through early November would seem to present the most temperate environmental conditions of the four month period. December presents the prospect of cold, stormy weather with sub-freezing temperatures.

SGRD-UE-EMT
SUBJECT: Heat Strain Model with and without Cooling for Climatic Conditions September - December at Fort Benning, GA

7. POC is Bruce Cadarette at extension 4835.

Michael N. Sawka

MICHAEL N. SAWKA, Ph.D.
Chief, Thermal Physiology and
Medicine Division

CF:
CPT M. Nugent
SIPE Ofc

TABLE 1. ENVIRONMENTAL CONDITIONS FOR SEPTEMBER - DECEMBER TAKEN FROM "1990 LIGHT DATA AND CLIMATOLOGY FOR FT BENNING GA".

	AVG HIGH TEMP (°C)	AVG LOW TEMP (°C)	%RH	%CLOUD COVER	WIND (KNOTS)
SEPT	30.6	18.9	58	50	2
OCT	25.6	12.2	48	40	2
NOV	20.0	6.1	51	50	2
DEC	15.6	3.3	53	50	3

TABLES 2A - 2C. WORK-REST CYCLES (MIN) PER HOUR AND MAXIMUM SINGLE WORK TIME (MIN) AT FOUR WORK INTENSITIES WITH NO COOLING DURING AVERAGE HIGH TEMPERATURES FROM SEPTEMBER - DECEMBER.

TABLE 2A. TIMES WITH LOW HEAT CASUALTIES (<5%).

	VERY LIGHT 150 W	LIGHT 250 W	MODERATE 425 W	HEAVY 600 W
SEPT	NL/NL	NFW/85	NFW/42	NFW/28
OCT	NL/NL	8/119	NFW/47	NFW/31
NOV	NL/NL	NL/NL	11/51	6/33
DEC	NL/NL	NL/NL	18/57	11/36

NUMBER TO LEFT OF / IS MINUTES OF WORK PER HOUR TO REACH CORE TEMPERATURE OF 38.5° WITH REMAINDER OF HOUR AT REST TO ALLOW CORE TEMPERATURE TO DROP. NUMBER TO RIGHT OF / IS MINUTES OF CONTINUOUS WORK BEFORE CORE TEMPERATURE REACHES 39°C.
NL = NO LIMIT
NFW = NO FEASIBLE WORK TIME

TABLE 2B. TIMES WITH MODERATE HEAT CASUALTIES (20 %).

	VERY LIGHT 150 W	LIGHT 250 W	MODERATE 425 W	HEAVY 600 W
SEPT	NL/NL	NFW/195	NFW/55	NFW/34
OCT	NL/NL	NL/NL	7/63	NFW/39
NOV	NL/NL	NL/NL	20/71	11/43
DEC	NL/NL	NL/NL	29/83	17/46

NUMBER TO LEFT OF / IS MINUTES OF WORK PER HOUR TO REACH CORE TEMPERATURE OF 39.0°C WITH REMAINDER OF HOUR AT REST TO ALLOW CORE TEMPERATURE TO DROP. NUMBER TO RIGHT OF / IS MINUTES OF CONTINUOUS WORK BEFORE CORE TEMPERATURE REACHES 39.5°C.
NL = NO LIMIT
NFW = NO FEASIBLE WORK TIME

TABLE 20. TIMES WITH HIGH HEAT CASUALTIES (50%)

	VERY LIGHT 150 W	LIGHT 250 W	MODERATE 425 W	HEAVY 600 W
SEPT	NL/NL	NL/NL	NFW/71	NFW/42
OCT	NL/NL	NL/NL	16/85	7/48
NOV	NL/NL	NL/NL	31/101	17/53
DEC	NL/NL	NL/NL	42/134	23/59

NUMBER TO LEFT OF / IS MINUTES OF WORK PER HOUR TO REACH CORE TEMPERATURE OF 39.5°C WITH REMAINDER OF HOUR AT REST TO ALLOW CORE TEMPERATURE TO DROP. NUMBER TO RIGHT OF / IS MINUTES OF CONTINUOUS WORK BEFORE CORE TEMPERATURE REACHES 40°C.

NL = NO LIMIT

NFW = NO FEASIBLE WORK

TABLE 3. NET EFFECT OF 15 SCFM AMBIENT AIR COOLING ON HEAT STORAGE (CHANGE IN MEAN BODY TEMPERATURE) WEARING NBC CLOTHING DURING MONTHLY AVERAGE HIGH TEMPERATURES FROM SEPTEMBER - DECEMBER FOR MODERATE AND HEAVY WORK INTENSITY.

	MODERATE 450 W	HEAVY 600 W
SEPT	EFFECTIVE COOLING	HEAT STORAGE
OCT	COOLING COLD DISCOMFORT	COOLING COLD DISCOMFORT
NOV	COOLING COLD DISCOMFORT	COOLING COLD DISCOMFORT
DEC	COOLING COLD DISCOMFORT	COOLING COLD DISCOMFORT

EFFECTIVE COOLING: SOLDIER ABLE TO THERMOREGULATE
HEAT STORAGE: MICROCLIMATE COOLING UNABLE TO FULLY COUNTER ENVIRONMENTAL AND METABOLIC HEAT

TABLE 4. NET EFFECT OF 5 SCFM AMBIENT AIR COOLING ON HEAT STORAGE (CHANGE IN MEAN BODY TEMPERATURE) WEARING NBC CLOTHING DURING MONTHLY AVERAGE HIGH TEMPERATURES FROM SEPTEMBER - DECEMBER FOR MODERATE AND HEAVY WORK INTENSITY.

	MODERATE 450 W	HEAVY 600 W
SEPT	HEAT STORAGE	HEAT STORAGE
OCT	EFFECTIVE COOLING	HEAT STORAGE
NOV	COOLING COLD DISCOMFORT	EFFECTIVE COOLING
DEC	COOLING COLD DISCOMFORT	COOLING COLD DISCOMFORT

EFFECTIVE COOLING: SOLDIER ABLE TO THERMOREGULATE
HEAT STORAGE: MICROCLIMATE COOLING UNABLE TO FULLY COUNTER ENVIRONMENTAL AND METABOLIC HEAT

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